A Metaknowledge Approach to Facilitate Knowledge Sharing in the Global Product Development Process

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ABSTRACT

Widespread adoption of the multi-functional stage-gate product development model and the emergence of the global product development have conspired to create various knowledge sharing problems. Three such knowledge problem categories were identified by the authors in an exploratory study at a multinational heating systems manufacturer. This paper presents the recent developments to an ontology-based knowledge sharing tool intended to tackle these problems and describes an industry-based case study intended to illustrate how the tool may be used in practice. The results of the study demonstrate how the tool addresses the knowledge sharing problem and thereby facilitates the sharing of knowledge in a global product development environment. The project was sponsored by the heating systems manufacturer and the UK Engineering and Physical Sciences Research Council (EPSRC).

Keywords: Global product development; ontology; metaknowledge

1. INTRODUCTION

It is widely acknowledged that new product development (NPD) makes a critical contribution to the success of manufacturing firms. Nevertheless, the development of new products continues to be a risky venture. A recent study conducted by the American Productivity and Quality Control and cited in Kahn, claimed that only roughly half of NPD projects are delivered on time or meet their financial targets [7]. Many researchers, including Jones and Stevens have argued that project failures are in part caused by the lack of a systematic approach to these complex projects and have encouraged the use of formal process models to support managerial decision-making [6]. In fact such models have been in increasing use by industry for the last forty years.

A commonly used model is the cross-functional stage-gate model, which according to Griffin is currently employed by over sixty percent of firms in the United States [5]. This model divides the NPD process into discrete stages, each of which is followed by a review gate. Each stage and review gate involves project team members from different functions within the organization, each of whom may also have different levels of experience and expertise. Activities within the process are linked by an exchange of information and knowledge among team members. As a result, effective communication is required to manage the activities in the NPD process, a view supported by Effendi et al [4]. In recent years, this situation has been further complicated by the emergence of global product development, a phenomenon driven by globalisation and supported by internet-based digital tools. MacDonough et al characterise global product development team members as being geographically dispersed, speaking different languages, and originating from different cultural backgrounds [9]. Collectively, these issues may be viewed as knowledge sharing challenges.

In order to investigate these challenges further, the authors carried out an investigation of knowledge sharing problems in the new product development process of a large European heating systems manufacturer, hereafter referred to as 'the company' [1]. Knowledge is defined as the information, skills and know-how used for, or generated by tasks in the NPD business process. This definition includes both the explicit knowledge dimension, essentially information, and the tacit knowledge dimension. Collectively, and combined with appropriate contextual information, these elements can be synthesised into knowledge in the minds of individuals. The company used the aforementioned cross-functional stage-gate model and uses project teams based in different countries. Importantly, this model closely adheres to the generic stage-gate models commonly presented in the literature. It is comprised of seven phases, including those of product strategy, product conception, functional design, detailed design, product and production process testing, industrialisation and post-launch project review. Furthermore, it features gateway reviews between each of these stages. Product development teams have all three of the traits characterising global product development teams described by McDonough et al. [9]. Three knowledge sharing problem categories were identified. Category A was the lack of an explicit definition of information about knowledge, or metaknowledge, in the new product development process. This information includes the knowledge inputs and outputs for each task, where the knowledge might be found and the priority of the knowledge. Court cites research suggesting that engineering designers use up to thirty percent of their time finding and availing themselves of such knowledge [2]. Category B referred to the challenges which arose from "the lack of a mechanism to make information about knowledge accessible to process users within a multidisciplinary, multilingual environment. This prevents team members from achieving what Kleinsmann and Valkenburg referred to as a shared viewpoint [8]. Lastly, category C concerned the lack of a mechanism to disseminate information about NPD process knowledge to team members who may be based in various locations around the world.

A number of researchers have sought to address knowledge sharing and broader knowledge management issues surrounding the NPD process, notably Ramesh and Tiwana [11], and latterly Donnellan and Fitzgerald [3], who adopted a metaknowledge approach. However both of these systems depend on the installation of significant additional information systems infrastructure, such as knowledge repositories and do not explicitly link information about knowledge to tasks in the NPD process. Furthermore they do not address the challenges of a multilingual environment. The authors proposed a methodology incorporating an ontology-based tool to address these problems and thereby facilitate knowledge sharing in the NPD process, a detailed description of which is provided in [1]. It is anticipated that likely users of the tool will be NPD project team members or project leaders. The previous work by the authors focused on an ontology of information about knowledge in the NPD process, thereby partially addressing problem category A, and a web-based mechanism to disseminate this information, thereby addressing problem category C. This paper builds upon the earlier research by describing the metaknowledge-based framework upon which the tool is based and introducing two newly implemented features. These features are a knowledge prioritisation mechanism and multilingual support mechanism, which address problem categories A and B respectively. In addition, the results of an industrial case study are described to illustrate how the tool may be used in practice to capture and disseminate information about NPD process knowledge.

2. KNOWLEDGE-SHARING TOOL

As already alluded to, an ontology-based tool approach was proposed to address the knowledge sharing problems described in the previous section. An ontology is 'a formal, explicit specification of a shared conceptualisation', as defined by Studer et al. [13]. A conceptualisation is a simplified view of the world, which is expressed as a model consisting of pertinent concepts in a knowledge domain. In this case the knowledge domain is the representation of information about knowledge in used and generated by tasks in the NPD process. The tool was created using version 3.0 of the Protégé ontology editor and knowledge-base framework software, as well as the Web Protégé browser tool [12]. This section begins with a brief overview of the system architecture and then goes on to outline the metaknowledge approach and the ontology upon which the knowledge sharing tool is based, followed by a description of the prioritisation and multilingual support mechanisms.

2.1 Overview of System Architecture

The knowledge sharing tool system is based on a client-server architecture**.** On the client side, a web browser such as Microsoft Internet Explorer® or Mozilla Firefox® is employed to visualise the ontology. The forms for capturing and viewing metaknowledge are created in the Protégé ontology editor and are reproduced in the web browser window (see Fig. 9). Users are able to navigate their way around the ontology using the familiar 'point and click' paradigm.

2.2 Metaknowledge Approach

Many past approaches to facilitate knowledge sharing in the NPD process have included a knowledge capture tool connected to a knowledge repository. One disadvantage of this approach is that it is difficult or time consuming to capture certain forms of knowledge, for example the advice of an expert about a decision on a previous project or a list of contacts who may be able to provide assistance with solving a problem. Another problem is that some companies, such as the company at which the knowledge sharing problems were identified, already have a large number of heterogeneous information systems. These include Enterprise Integration Systems such as SAP®, network drives and CAD systems.

Court posited that an important attribute for an information system used in new product development is an ability to act as a reminder of where information is located [2]. The approach adopted here then is to provide information about the knowledge 'packets' or items required or created by each task in the NPD business process. This should help NPD project team members to find relevant knowledge more easily, which may help to prevent project delays. Using metaknowledge in this fashion creates a level of abstraction that allows tacit and explicit knowledge to be described in the same system, thus avoiding the complications associated with capturing tacit knowledge. It also means that that no large monolithic systems must be installed. Rather, the tool should be viewed as a compliment to existing knowledge and information repositories. In the case of the tool proposed here, only a web server must be set-up. It should be conceded however, that this approach does nothing to prevent the knowledge held by individuals from being lost to the ravages of time or organisational renewal.

2.2.1 Ontology

There now follows a description of the principles behind the ontology used in the knowledge sharing tool. The purpose of the ontology was to form the basis of an application to provide information about NPD process knowledge (NPD process knowledge metaknowledge) to process users working in multinational, geographically dispersed teams. This application is intended to answer questions these users might have about this knowledge, such as 'what knowledge is required for, or generated by, a given process task?' and of this knowledge, were is it located, what format is it in, what priority does it have in terms of its strategic importance to the organisation and so on. Essentially, these are the competency questions that the ontology must answer. Key concepts in the NPD knowledge metaknowledge domain can be divided into three groups. The first group is the knowledge generated or required by NPD process tasks, which are represented by the 'knowledge item' concept. The second group contains various metaknowledge concepts, e.g. the format of the knowledge item (a report or perhaps advice from a colleague) or the repository in which it is stored (information system or human). The third group of concepts relate to information about the NPD business process itself, that is, the tasks and sub-processes that make up the NPD business process. It will be seen later on that this last group forms an important reference point for users of the tool.

By assigning properties to these concepts, the concepts can be linked together, thereby forming a lightweight ontology that formally defines relationships between concepts in the domain of NPD process knowledge. Consider for example the knowledge item concept. This concept has properties assigned to it that link it to various concepts in the metaknowledge group and to the NPD process task concept, In the Protégé knowledge model, concepts are described by classes, while slots describe the properties of these classes. A high level view of the taxonomy devised for the NPD process knowledge metaknowledge ontology is depicted in Fig. 1.

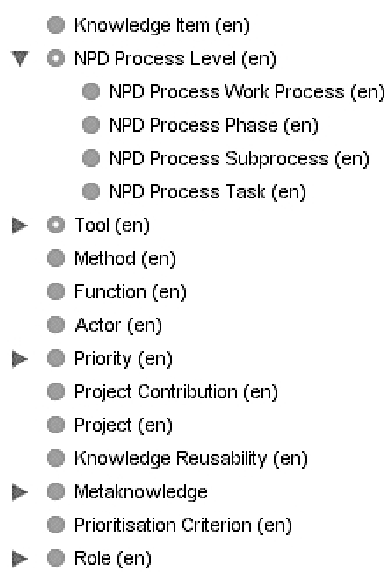

Fig. 1: The taxonomy used as the basis of the NPD process knowledge metaknowledge ontology.

In order to use the ontology as the foundation for a knowledge base application, instances of the classes must be created, as outlined in the methodology by Noy and McGuinness [10]. For example, an instance of the 'knowledge item' class might be the 'how and whys' of a decision taken in a stage-gate review meeting. Through the creation of class instances, knowledge used in the NPD process and information about that knowledge can be added to the knowledge base, providing answers to the kinds of questions posed earlier in this section. This principle is illustrated in Fig. 2. In the Protégé ontology editor tool, creating an instance of a class results in the creation of a form that that includes the slots assigned to that class. The values for these slots must then be chosen; slots assigned to the knowledge item class would point to the instances of the 'NPD Process Task' class and to instances of the various metaknowledge classes.

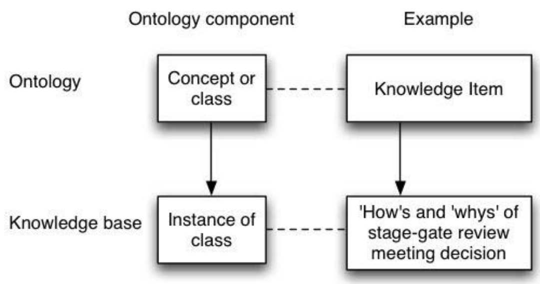

Fig. 2: The relationship between classes and instances accompanied by illustrative examples.

It is envisaged that a process user will navigate the instances of NPD process tasks in the knowledge base relevant to their role in order discover information about pertinent knowledge items. The NPD business process provides a common reference point because it is used by all the functions participating in an NPD project. Indeed, the classes describing the process itself constitute the backbone to the ontology. A project team leader or manager, on the other hand, may wish to understand the significance of a given knowledge item within the process and seek information such as the tasks that require that knowledge. This approach is not specific to heating systems design. Minor adaptations to the class taxonomy, especially the subclasses under the NPD Process level class shown in Fig. 2, should make the tool suitable for use with any formal product development process conforming to a linear stage-gate model and involving new product projects of similar complexity. However, the tool may be impractical in instances where there are large numbers of knowledge item inputs and outputs for process tasks. This is because of the resulting difficulties in navigating these items and the time required to add the appropriate metaknowledge using the slots.

2.2.2 Implementation

Prior to implementing the metaknowledge framework, it was necessary to understand what metaknowledge the NPD process teams would require. This was achieved in three stages. In the first stage, the five 'W's and one 'H' approach of journalistic enquiry was applied to determine the basic information a user may wish to know about a task or knowledge item. In the second stage, the information for a knowledge item was compared to the Dublin Core metadata element set proposed by Donnellan and Fitzgerald [3] to create a prototype set. In the third stage, the prototype metaknowledge element set was placed on a mind-map and presented to four NPD project leaders in the company. The project leaders were asked two questions: (1) whether they felt any of the metaknowledge elements were unnecessary, and (2) what metaknowledge was missing. Following this the requested adjustments were made to the prototype metaknowledge set. Implementation of the required metaknowledge set into the ontology was achieved by using each metaknowledge element as the basis for formulating a competency question that the ontology should answer. In practice, this meant that a 'relationship' must be created in the ontology for each element of metaknowledge and assigned to the 'knowledge item' and 'task' concepts. The metaknowledge and corresponding relationships for a knowledge item is listed in Tab. 1.

Description of Metaknowledge Element	Corresponding property or 'slot' in ontology
Languages in which item is available	available_in_language
Is an output from task	generated_by_task
Knowledge contributions from previous projects	has_expert_contribution

Functional domain to which knowledge item belongs	has_knowledge_domain
Knowledge item medium	has_medium
Other versions of knowledge item	has_other_version
Owner of knowledge item	has_owner
Prioritisation criterion assigned to knowledge item	has_prioritisation_criterion
Repository in which knowledge is stored	is_stored_in_repository
Description of knowledge item	knowledge_item_description
Format of knowledge item	knowledge_item_format
Location of knowledge item	knowledge_item_location
Title of knowledge item	knowledge_item_title
Is an input for task	provides_knowledge_for_task

Tab. 1: Knowledge metaknowledge element set.

2.2 Prioritisation Mechanism

The aims of the prioritisation mechanism were, firstly to provide a means of indicating the priority of a given knowledge item and secondly to provide a way to assign criteria to each priority level. For example, it might be decided by a company that their main strategic goal was to focus on product quality. In this case, it may be desirable to assign a 'high' priority to all knowledge related to quality and indicate this to NPD project members. Four key stages are required to implement this scenario. Stage one involves the creation of the desired 'priority levels' under the 'priority' class in the browser window, as shown in Fig. 3. Here, three priority levels have been created: low, medium and high. A symbol has been assigned to each level to quickly indicate the knowledge item priority to users. Low priority items are assigned a single star ('*'), medium priority knowledge items with two stars ('**') and high priority items are indicated with three stars ('***'). Stage two consists of adding the criteria by which the knowledge items are to be prioritised. In this example, four criteria are included: function, time, cost and quality (see Fig 4). Finally, stage three involves opening the form for a given knowledge item and selecting the criterion that best describes that knowledge.

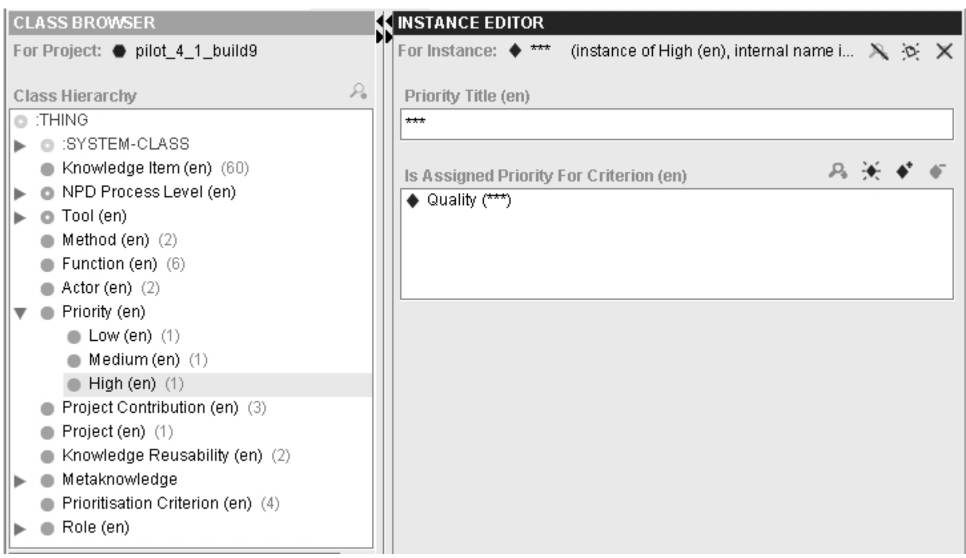

Fig. 3: The 'priority' class with low, medium, and high priority level concepts as subclasses.

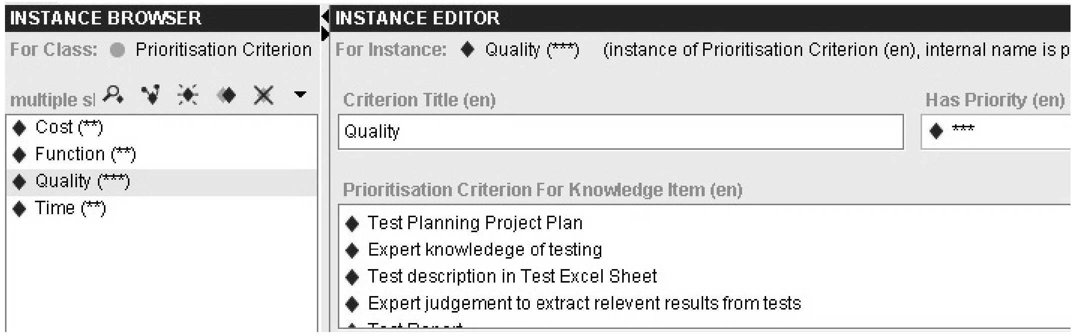

Fig. 4: A priority can be assigned to each prioritisation criterion. Listed below the criterion title are the knowledge items to which it has been assigned.

2.3 Multilingual Support Mechanism

A limited level of multilingual support has been provided using the 'metaclass' and 'metaslot' editing functionality in the Protégé ontology editor [12]. This feature makes it possible to add a label for a given language, such as French or Spanish, to the concepts (classes) and relationships (slots) used in the tool. It is then possible to display the label language for the desired language in place of the default class and relationship names. A similar approach has been adopted to allow the addition of synonyms. This may be useful in situations where different terms may be used by different functional disciplines in the company to describe the same NPD knowledge concept. Although the synonyms cannot be displayed in the same manner as the multilingual labels, they can found by the search engine included in the Protégé Web Browser client bundled with the Protégé editor. It should be acknowledged that there are certain limitations to this approach. Multilingual labels can be assigned to classes and slots, but not to instances in the ontology. This means that the knowledge items themselves are only available in a single language. Nonetheless the multilingual interface should help users of the tool to identify and find sources of knowledge more easily, regardless of their linguistic skills or functional backgrounds. In this way, the concepts and relationships represented in the ontology can be made comprehensible to a multilingual, multidisciplinary project team.

3. INDUSTRIAL CASE STUDY

An industry-based case study was undertaken in order to illustrate and test the functionality of the tool and to test the validity of the knowledge classification in the ontology. The company is a manufacturer of physical, electromechanical goods and uses a multifunctional stage-gate business process model to support its new product development projects. Many of the new products produced by the company are variations on previous designs. The model consists of five stages: strategy, conception, development, production and project review. Given that the NPD process consists of dozens of sub-processes and hundreds of tasks, it was decided that the scope of the investigation should be limited to the knowledge inputs and outputs for the tasks in three sub-processes. To demonstrate the multilingual support mechanism, the ontology is presented in English and German versions.

3.1 Method

The method used in the case study consisted of five steps. These steps were: (1) selection of the three sub-processes, (2) elicitation of information about the tasks from which the sub process is comprised, (3) elicitation of information about the knowledge required for and generated by these tasks, (4) capture of this information or metaknowledge in the knowledge sharing tool and finally, (5) translation of the English language concepts and relationships that form the ontology into German and addition of the multilingual labels. A more detailed explanation of each of these stages follows:

3.1.1 Selection of Candidate Sub-processes

Selection of the candidate sub-processes was carried out according to two main criteria. The first criterion was that the processes should involve the use of knowledge from a range of functional areas e.g. Marketing, Research & Development, Testing and Validation, Purchasing and so on. This was intended to indicate the broad spectrum of knowledge involved in new product development and provide a limited test of the knowledge classification in the ontology. The second criterion was that collectively the sub-processes should not be restricted to technical engineering processes. While engineering plays a critical role in product development, NPD projects involves many other issues, such as project management and the control of cost.

3.1.2 Elicitation of Information about the Tasks in Sub-processes
This step involved elicitation of information about the processes and tasks themselves, so that the NPD business process could be modelled in the tool. This was achieved through analysis of the full NPD business process documentation, which had already been secured from the company.

3.1.3 Elicitation of Information about Input and Output Knowledge
Information about the knowledge required for, and generated by the tasks in the three sub-processes was elicited from two sources. The first source was the aforementioned NPD business process documentation, which provides an indication of data and information inputs and outputs for some of the tasks. The second source was a semi-structured interview with the expert designated by the company for each process. This provided a much richer understanding of the different kinds of knowledge associated with each task.

3.1.4 Capture of Information about Knowledge
The penultimate step was executed out in two parts. The first part involved adding information about the sub-processes and tasks to the NPD process classification already implemented in the ontology. The second part involved creating the relevant knowledge items for each of the tasks created in the tool and then adding the metaknowledge using the graphical user interface.

3.1.5 Translation of Concepts and Relationships
In the final step, German language labels were added to the 'concepts' and 'relationships' in the ontology. Using this method, a German version of the tool interface was created. It should be noted that the translation is of a 'rough' nature and was conducted for illustrative purposes only. The NPD process documentation provided by the company served as an additional source of technical vocabulary.

3.2 Results
Following a review of the NPD business process, it was decided to select the three sub-processes from the product conception phase. This phase is both knowledge intensive in nature and exploits knowledge from a range of disciplines. Tab. 2 lists the selected processes, accompanied by a brief description. The 'generate product proposal' process is mostly of a technical nature, while the 'product validation' involves the use of knowledge from a broad range of functional domains. In contrast, the tasks in the 'project performance' process use and generate knowledge associated with the end of phase stage-gate review. This includes technical, cost and project management knowledge. As a result, the two selection criteria are satisfied.

Process Title	Description
Generate product proposal	Create initial product specification and prototypes from marketing proposal
Product validation	Test product concept and assess reliability
Project performance	Verify that NPD project is running to the agreed time, cost and process.

Tab.2: Selected sub-processes.

For reasons of brevity, only one of these processes, 'project performance', will be discussed here. However the example should prove sufficient to illustrate the key functionalities of the tool. As mentioned in the previous section information about the sub-processes and tasks was transferred to the knowledge sharing tool using the Protégé Ontology editor. The result of this procedure is shown in Fig. 5. The middle pane of the tool browser window shows the three processes. Selecting a process using a mouse pointer shows a list of the tasks belonging to that process in the right-hand pane.

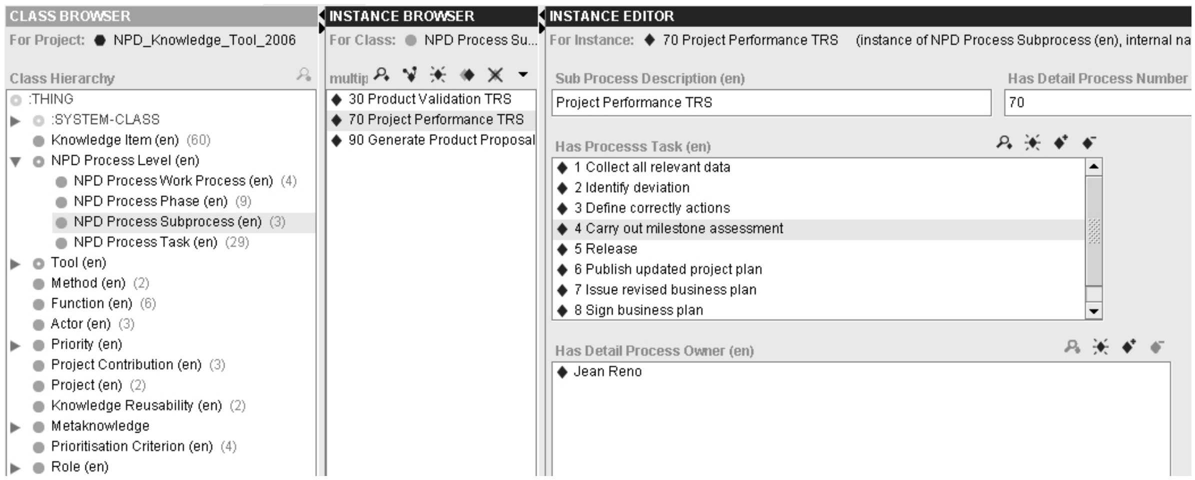

Fig. 5: Sub-process form in Protégé Editor.

Selecting a task allows the tool user to add its input and output knowledge items (*see* Fig. 6(a). Once this exercise is complete, the metaknowledge may be added to each knowledge item, as shown in Fig 6(b). This metaknowledge includes the priority assigned to the knowledge item; see boxed area in Fig 6(b), and expert contributions to the knowledge item made in previous projects, as depicted in Fig 7. Such contributions might include the rationale behind a decision taken during a project review meeting.

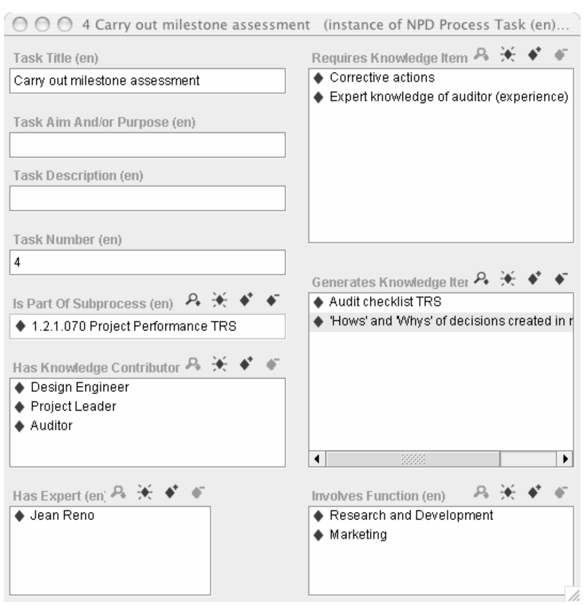

Fig. 6(a): Task form from 'project performance' sub-process. Fig. 6(b): Knowledge item form.

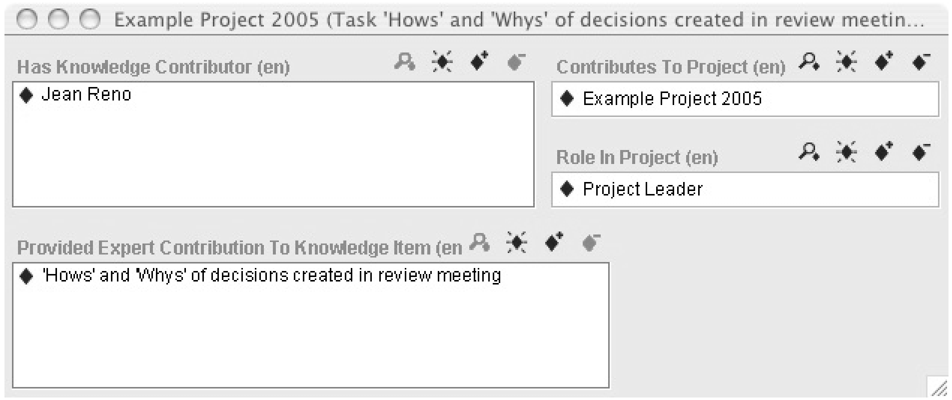

Fig. 7: Expert knowledge contribution form to document contributions made to knowledge item in a previous project.

All of this information may then be viewed remotely through a web browser interface, making it accessible to NPD project team members irrespective of their geographical location. An illustrative screenshot is provided in Fig. 8, which also shows the result of implementing the multilingual labels to create a German language version of the ontology.

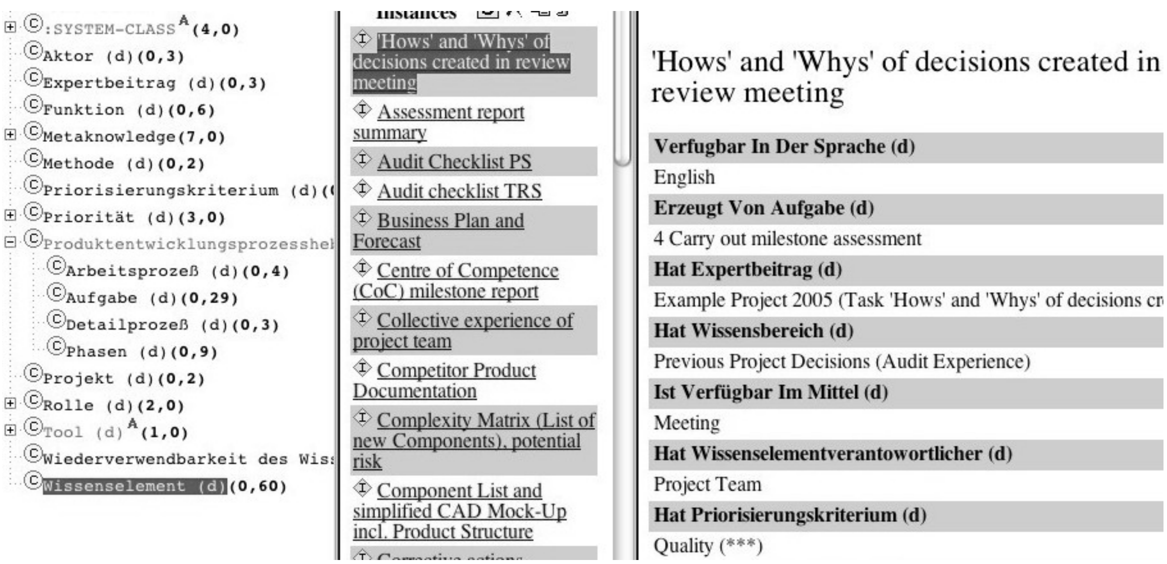

Fig. 8: Knowledge item form in the web browser interface (German version).

4. CONCLUSIONS

A metaknowledge approach has been applied to tackle three knowledge sharing problems identified in the new product development process of large, multinational heating systems manufacturer. The approach was realised using an ontology-based tool, which provides mechanisms to prioritise knowledge and supports a multilingual ontology interface, in addition to a web-based dissemination mechanism. The ontology explicitly defines the relationships between various concepts in the NPD process knowledge domain, including the knowledge required or generated by NPD process tasks, the metaknowledge which provides a range of contextual information about this knowledge, and the NPD business process itself. By linking NPD knowledge to tasks in the NPD business process, project team members are provided with a common reference point for accessing information about knowledge relevant to their needs. A case study examining the knowledge associated with tasks in three sub-processes in the NPD business process of a heating systems company has demonstrated how the tool and mechanisms may be used to capture and disseminate information about this knowledge. In this way, it has been shown how the tool might facilitate knowledge sharing in a global product development environment. Furthermore, given the close adherence of the case study company NPD process model to generic stage-gate models in the literature, it is proposed that the ontology employed in the tool could be adapted to suit the needs of other multinational manufacturing companies using a cross-functional stage gate model. Nonetheless, a similarly detailed business process would be required to model the process hierarchy in the ontology and it is likely that the tool user interface would be ill-suited to highly complex development projects where many knowledge inputs and outputs might be present for each task. Finally, it should be noted that the multilingual support mechanism is limited in scope to the classes and slots in the ontology and does not extend to the data. Additionally, the level of usefulness of the tool to potential users has yet to be formally assessed. Further research then, should focus on these issues.

5. ACKNOWLEDGEMENTS

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