A Methodology for Problem-Driven Knowledge Acquisition and Its Application

Yin Gai[1(✉)], Yanzhong Dang[2(✉)], and Zhaoguang Xu[2]

[1] School of Management Science and Engineering, Dongbei University of Finance and Economic, Dalian, Liaoning Province, People's Republic of China
gaiyin@dufe.edu.cn

[2] Institute of System Engineering, Dalian University of Technology, Dalian, Liaoning Province, People's Republic of China
dangyanzhong@dlut.edu.cn

Abstract. Most papers claim that knowledge acquisition is a critical bottleneck and has become an important research issue in knowledge management. However they take very different perspectives on it and there is little agreement on how it should be implemented in the industry. In this paper, we investigate problem solving as a cognitive process and propose a new and practical methodology for problem-driven knowledge acquisition. Our contribution includes: (1) proposing a model for problem-driven knowledge acquisition at cognitive level which integrates cognitive structures of problem solvers with situations of knowledge acquisition; (2) designing a framework for problem-driven knowledge acquisition which implements knowledge structured from prior practical experience; (3) developing a prototype system and implementing a mechanism of problem-driven knowledge acquisition. Our proposed methodology has been applied in a real practice case. The results demonstrate that the prototype system can be an effective tool for enterprise-wide knowledge management practice.

Keywords: Problem-driven · Problem solving · Knowledge acquisition · Knowledge management

1 Introduction

Knowledge undoubtedly represents the main competitive advantage of an organization. It refers to what one knows and understands. It is "meaningful links people make in their minds between information and its application in action in a specific setting" [1]. That is to say, knowledge can be viewed both as a thing to be stored and manipulated and as a process of simultaneously knowing and acting [2]. In the industry, knowledge refers to the sum of information relevant to a certain job, and usually we get things done successfully by knowing an answer or how to find an answer, or knowing someone who can [3]. Since knowledge has become important for individuals and organizations increasingly, knowledge management has been widely proposed as a methodology that can manage knowledge in organizations [4]. The idea about knowledge management is simple: apply knowledge to a work environment in order to create value.

J. Chen et al. (Eds.): KSS 2016, CCIS 660, pp. 82–93, 2016.
DOI: 10.1007/978-981-10-2857-1_7

In this context, acquiring and creating knowledge is a key issue to improve the performance of organizations over time. However, acquiring knowledge is difficult in organizations for three main reasons: (1) knowledge is often implicit – it lives in the minds of individuals. Therefore, it is difficult to transfer knowledge to another person by means of the written word or verbal expression; (2) knowledge is situated – it is created in a context, so it cannot be used reliably out of context where it is created; (3) knowledge acquisition is a cognitive process – it involves both dynamic modeling and knowledge generation activities.

In order to overcome these difficulties, a wide variety of organizational knowledge management practices have been proposed to support knowledge acquisition, storage and creation involving ideas from different research areas, such as psychology, sociology, philosophy, and computer science [5, 6], yet the process how humans acquire knowledge is not clear [7, 8].

All life is problem solving [9]. Problem solving is in the center of daily operations for organizations. Workers are required to organize complex projects, deal with interpersonal conflicts, and develop innovative products. Since 1980s, problem solving is considered as an important, if not the most essential, feature of learning by many instructional models like Constructivist Learning Environments, or Problem-based Learning [10]. In the decades, problem solving that requires searching and sharing knowledge among a group of actors in a particular context becomes an important issue in knowledge management [11, 12]. Problem solving may enable or inhibit an organization's or an individual's ability on problem solving [13–15]. The researches of problem solving may provide some guidance for the design of organizations to support knowledge acquisition and generation [16–18].

By focusing attention on the importance of problem solving as a cognitive process, this study proposes a new way to understand the connection between problem solving and knowledge acquisition as well as a methodology for problem-driven knowledge acquisition. The methodology is connected with: (1) accumulating and formalizing prior knowledge acquisition at cognitive level, (2) presenting a cognitive knowledge model for a new problem solving, and (3) integrating new knowledge into existing knowledge and experiences. The main goal of this study is in two folds. First, it aims to introduce a framework that can be used for knowledge acquisition driven by problem solving in daily work. Second, it aims to develop a problem-driven knowledge management methodology to support organizational knowledge management practice. Our work differs from existing literature in the following ways: (1) it incorporates cognitive structures of problem solvers with situations of problem solving into the knowledge acquisition model, (2) it analyzes how this methodology can be successfully applied into enterprise-wide knowledge management practice.

This paper is organized as follows. Section 2 analyzes the process of problem solving in coherence with the theories of cognitive psychology and knowledge management practice. Section 3 proposes a model for problem-driven knowledge acquisition at cognitive level, and designs a framework consists of two phases with six steps correspondingly. An application case of the methodology for problem-driven knowledge acquisition is provided in Sect. 4. Finally, Sect. 5 concludes and presents some future research extensions along with this work.

2 Problem Solving

From the view of cognitive psychology, there are many theories proposed about the cognitive process of problem solving [19, 20]. Generally, the process of problem solving is divided into several stages with different features in each stage. Based on these theories about the process of problem solving and knowledge practice, in this paper the process of problem solving is divided into five stages: Describing, Analyzing, Proposing, Implementing and Evaluating, as shown in Fig. 1. In fact, the process of problem solving is often in a spiral pattern so that the problem can be solved completely.

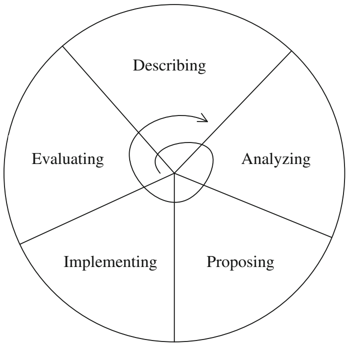

Fig. 1. The five stages of problem solving process

Stage (1): Describing

Problem solving usually begins with some description about the problem situations, as well as the initial state and the terminal state. The problem situations include the time, space and characters during the process of problem solving; initial state includes the conditions or phenomena that can be directly observed or tested when the problem happened; the terminal state includes the expected states that can be achieved when the problem is solved completely.

Stage (2): Analyzing

Causes associated with the problem are analyzed and the successive causality among them is then to be traced. Usually, the causes associated with the problem should be reviewed and analyzed from the surface cause to the root one. In other words, analyzing these causes is a process from the outside cause to the inside one, and from the shallower cause to the deeper one about problem solving.

Stage (3): Proposing

Proposing the schema is to solve a specific problem and to give the specific plans. Usually, the proposed schema is to find a variety of solutions according to the causes after the analyzing stage (2). In general, appropriate solutions are proposed for the root causes correspondingly in order to solve the problem completely. And for a relatively complex problem, the root causes may not be single.

Stage (4): Implementing

In fact, many problems could not be simply implemented according to the schema from stage (3), because each problem solver has an individual's preferences and traits. Besides, it must be in line with the incorporation of information from multiple sources of problem solvers' knowledge, perspectives, and experiences, as well as the enterprise's resource that can be obtained.

Stage (5): Evaluating

Although, the problems get solved from stage (1) to stage (4) or expected states are finally achieved, the knowledge or experience during the process of problem solving should be evaluated that may be applied into the subsequently problem solving. So that, the knowledge or experience will continue to promote by the evaluating stage (5).

3 The Methodology

3.1 The Model

In cognitive psychology, problem solving is the cognitive process that implies the efficient interaction between cognitive structures of problem solvers and situations during problem solving. Through analyzing and understanding the cognitive contents of problem solving, two-levels of knowledge are contained at least during the process of problem solving. One is surface-level knowledge which is related to a specific problem, e.g. the details about the problem, the time and space, some issues involved in the process of problem solving, and so on. The other is deep-level knowledge which is general for any problem, e.g. the basic principle, the constraint or the rule, the essence of the problem, and so on. Although there may be differences among different problems, the cognitive structures that has been inherited in the brains of problem solver are common. Therefore, if the surface-level knowledge is abstracted as many situational dimensions and the deep-level knowledge is formalized as a cognitive network respectively, the conceptual model of problem-driven knowledge acquisition is proposed in Fig. 2.

Specifically, in Fig. 2 one situational dimension represents a certain type of situational elements that may be involved in the process of problem solving, such as persons, time, space, and so on. In each situational dimension there is a certain inherent logic

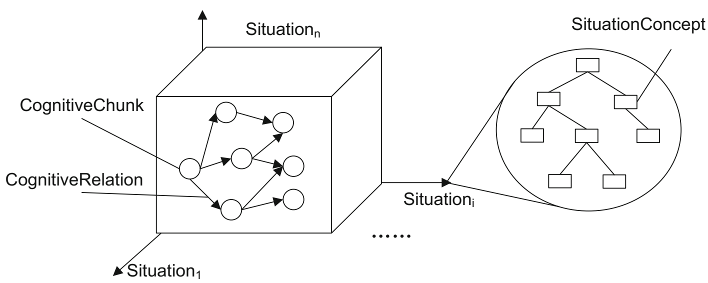

Fig. 2. The conceptual model of problem-driven knowledge acquisition

relation itself. For example, the organizational structure among persons, the sequence of time, the scope and overlapping relations of space, and so on, so that it also can makes more detailed analysis on each situational dimension according to the characteristics of the domain knowledge. The cognitive network is composed of a series of nodes and their relations. One node represents a cognitive chunk, which is a knowledge unit and composed of knowledge points with a certain logical structure. One cognitive chunk has some significant meanings about problem solving. The cognitive chunks are connected through cognitive relations, so that the problem can be transformed from the initial states to the expected states, and finally the problem can be solved.

Generally, the conceptual model integrates the surface-level knowledge which is related to a specific problem with the deep-level knowledge which is general for any problem. The surface-level knowledge is very important for knowledge acquisition, because problem solvers will applied the prior knowledge or experience into any new problem in according to the surface-level knowledge. The deep-level knowledge is inherent in problem solvers' brains which is obtained during the prior process of problem solving.

3.2 The Framework

A framework for problem-driven knowledge acquisition is designed based on the conceptual model proposed in Sect. 3.1. The framework of problem-driven knowledge acquisition consists of two stages with six steps which implement formalization from practical experience to structured knowledge, as shown in Fig. 3.

In the first stage, the practical experience form problem solving is transformed to the semi-structured knowledge. In the second stage, the semi-structured knowledge is formalized to the full-structured knowledge. The following describes the six steps in the framework in detail.

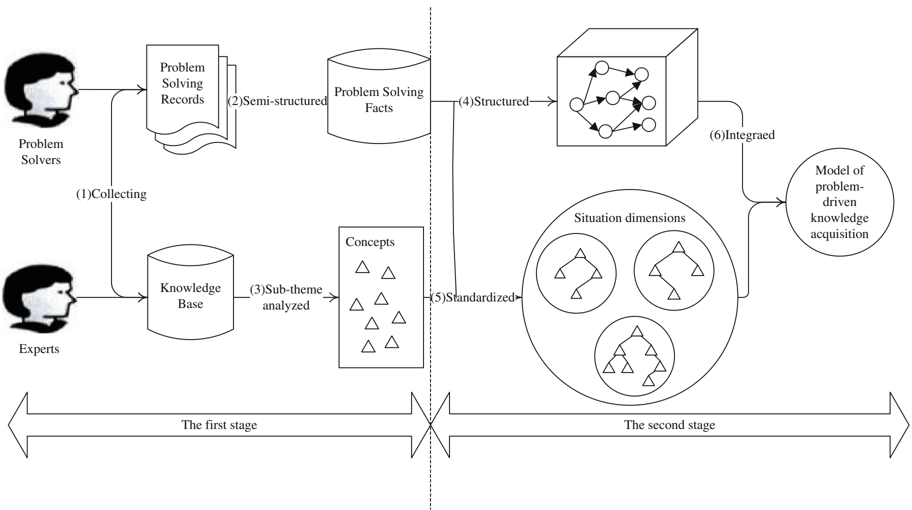

Fig. 3. The framework of problem-driven knowledge acquisition

Step (1) collecting

Under the coordination of decision makers, managers, senior technicians, and the front-line workers, the knowledge engineers endeavor to collect related records during the processes of problem solving and domain knowledge base.

Step (2) semi-structured

According to the five stages about the process of problem solving proposed in Sect. 3, the experience in the records and knowledge base can be semi-structured to problem solving facts.

Step (3) sub-theme analyzed

There are many particular knowledge domains in related to problem solving, so the knowledge base must be analyzed according different aspects about the processes of problem solving. After that, some concepts or words about different knowledge domains are obtained.

Step (4) structured

The problem solving facts are abstracted to a cognitive network with cognitive chunks and their relations. The cognitive network is structured so that the knowledge can be applied into the subsequent problem solving by knowledge retrieval and knowledge organization.

Step (5) standardized

The concepts or words are classified into different situational dimensions, and the standardized terminology is formed. Also, the situational dimensions provide a standardized of the semantics required for knowledge application.

Step (6) integrated

The cognitive network from step (4) is integrated with many situational dimensions from step (5), and the model of problem-driven knowledge acquisition is constructed finally.

4 The Application

This section presents the results of a case study about management practices of the methodology of problem-driven knowledge acquisition, and we have developed a knowledge management prototype system applying the methodology in the workshop for line-stop problems on automatic production lines. We have deliberately simplified the methodology to provide understandable explanations.

4.1 Background

To begin with we will provide a brief background on the case study. This enterprise involved in this practical study is a car manufacturer. In car manufacturing, the stamping process is an important way of metal forming. In order to manufacture mental parts, stamping workshops of modern auto-mobile industry usually use flexible and efficient automatic production lines. There are five automatic production lines in the example stamping workshop, and Line A and Line B are the main production lines. There are various types of stamping molds on Line A and Line B with 2200 stamping molds in the workshop. The productivity of a production line depends not only on how many working strokes, but also on the stop-line time of production line. According to the investigations, the average stop-line rate of production lines in the stamping workshop is as high as 21.6 %, which has brought to the workshop big loss in economy and credibility. Therefore, how to solve stop-line problems on the production lines effectively can not only help the enterprise to reduce production costs, but also meet the urgent needs for just-in-time production.

Usually, when stop-line problems happened, the phenomena on the production line can occur in a variety of ways, and these phenomena often occur overlap together, which have brought great difficulty to restore the production line in a short time. During the process of problem solving, stamping experts are usually able to make correct judgments rapidly by combing pieces of cognitive chunks together in an unconscious process. But when they attempt to explain the problem solving process, it takes often an in-complete and non-sequential form that is not suitable for knowledge acquisition and communication. Even if the relevant participants records the experience, but due to the lack of a structural framework for guidance, important knowledge or experience is difficult for communicating and sharing. And with the expansion of production and update of technology, more and more stop-line problems will occur frequently. Therefore, the aim is to identify technical support for collecting and reusing knowledge and experience about problem solving.

In this project, we employ the methodology for developing a problem-driven knowledge management prototype system so that the workers and managers in the stamping workshop can apply it for providing feedback and guidance to their problem solving and knowledge management.

4.2 The Model of Stop-Line Problem-Driven Knowledge Acquisition

Technicians and experts have much experience about stop-line problem solving from practice over the years. Capturing the experience and knowledge, storing them and distributing them within and across the stamping workshop, are important issues in workshop management. To obtain first-hand information and problem solving experience, we collected the loggings of stop-line problem solving processes from 2012 to 2013, and all the information collected for the project is stored on a local server. Then, we discussed and communicated with experienced technician and experts to understand the stamping process. Finally, we filed 1459 semi-structured records of stop-line problem solving processes stored as Excel sheets, as in Fig. 4. Some English notes have been added in the table headers to describe the problem sheet. Each experience record includes five contents: describing, analyzing, proposing, implementing and evaluating. According to the contents and structures provided in the check sheet, relative participants can express the problem solving process in detail.

Figure 5 shows a cognitive network according to problem solvers' cognitive structures during the process of stop-line problem solving. The cognitive network of the strop-line problem includes two kinds of cognitive chunks: declarative and procedural. Declarative and procedural chunks are separately used to describe some causes and solutions during the process of problem solving. After abstracting from the excel

Problem number 问题编号	When the Problem occurs 问题发现时间	Related departments 来源部门	States of the problem 问题状态	Type1 of the problem 分类1	Type2 of the problem 分类2	Car model 车型	Product variety 生产品种	Production process 工序	Production line 生产线	Production team 班组	Down time 停机时间	Problem title 问题标题
234	2012/2/6	0000	05	02	01	D82A	左侧围		A线	生产乙班（三班）	57	修边切不断
235	2012/2/6	0000	05	02	01	B50	左侧围		B线	生产乙班（三班）	45	op20卡废料频繁
236	2012/2/6	0000	05	02	01	B50	左侧围		B线	生产乙班（三班）	45	op20卡废料频繁
237	2012/2/6	0000	05	02	01	B50	左侧围		B线	生产乙班（三班）	45	op20卡废料频繁
238	2012/2/6	0000	05	02	01	B50	左侧围		B线	生产乙班（三班）	45	op20卡废料频繁
239	2012/2/7	0000	05	02	01	B50	左右支柱内板下部	02	B线	丙段	5	Op20堵废料

Fig. 4. Stop-line problem solving processes stored as excel sheets

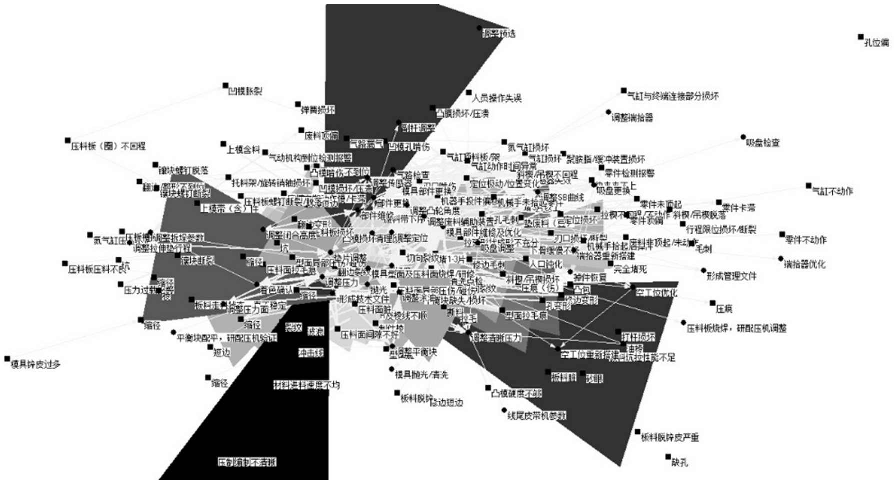

Fig. 5. The cognitive network of stop-line problem solving

sheets, our study get 117 declarative cognitive chunks and 42 procedural cognitive chunks. While circle nodes demotes the declarative cognitive chunks, square nodes denote the procedural cognitive chunks. The thickness of the link between nodes means the probability of the various chunks. The cognitive network offers the visualization for problem analysis and solution.

Figure 6 presents the generalized situations, which encompasses person, equipment, material, technique, and environment situation. Five situational dimensions are constructed for stop-line problem solving on the production lines. A domain expert or manager's role comprises setting up a hierarchy, connecting situational concepts to the dimension. Each situational dimension also can be refined and expanded gradually so

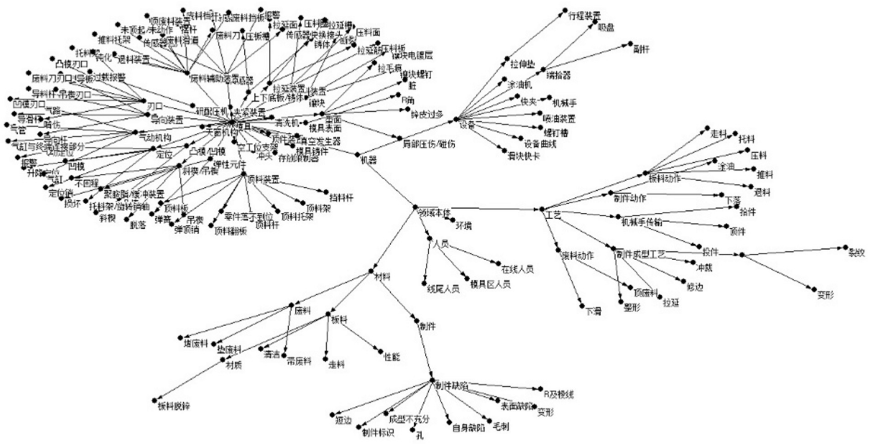

Fig. 6. The situational dimensions of stop-line problem solving (part)

that these dimensions can also be used for indexing and retrieving knowledge. This study defined 519 concepts about these situational dimensions of stop-line problem solving. In the Fig. 6, a part of the concepts and their relationship is showed.

4.3 The Architecture of Stop-Line Problem-Driven Knowledge Acquisition

Based on the cognitive process of problem solving and knowledge management techniques in industry, the architecture for problem-driven knowledge management is developed to effectively support knowledge capitalization and exploitation in each stage of problem solving, as shown in Fig. 7. This designed architecture has four layers: the knowledge base and repository layer, the problem solving model for knowledge acquisition layer, the knowledge application layer and the participant layer.

On the bottom of the architecture in Fig. 7, there are an experience base and a domain knowledge repository. Information and knowledge directly acquired during problem solving are stored to a Problem Solving Experience Base by problem solvers. Each experience is saved as a detailed and semi-structured description of problem solving according to the five stages of problem solving process. Besides, the resources for all the domain information related to problem solving come primarily from the domain knowledge repository, e.g. engineering hand-books, product specification, product functionality, and manufacturing process specification files.

The model for stop-line problem-driven knowledge acquisition is a cognitive network with multi-situational dimensions which incorporates cognitive structures of problem solvers and situations of knowledge acquisition in order to support knowledge acquisition.

Knowledge application layer consists of a problem-solving module, a decision-making module, a knowledge learning module and a knowledge retrieval module. In the problem-solving module, progressive tools are designed to guide problem solvers to

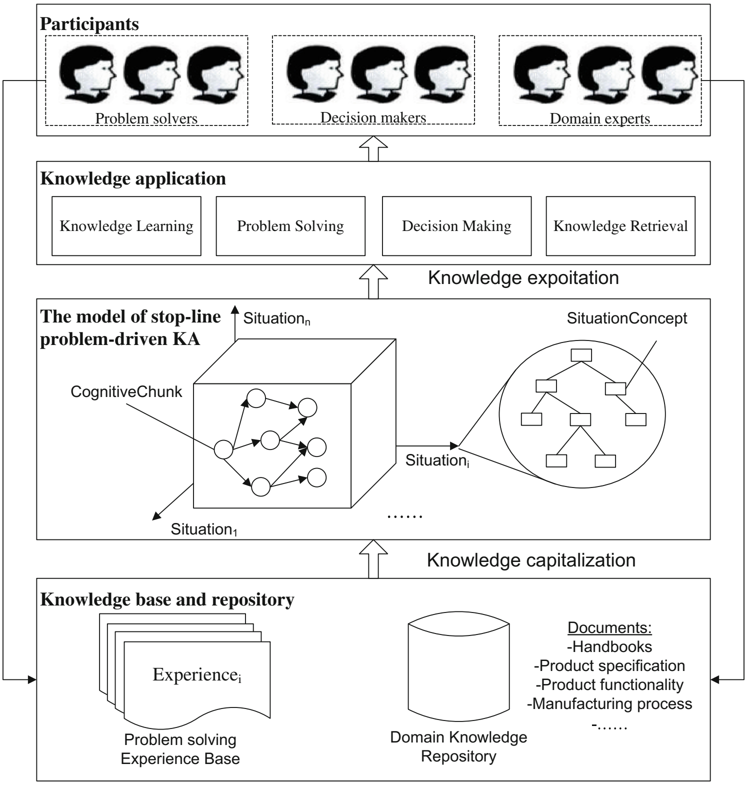

Fig. 7. The architecture of problem-driven knowledge management system

conduct problem solving activities, including requirements description, analysis/ simulation, experiences description, and so on. In decision making module, relative tools help decision makers to collect, analyze, and evaluate knowledge of problem solving. In knowledge learning and retrieval module, the participants can be guided to browse, retrieve, and trace knowledge.

This designed architecture has three types of participants: problem solvers, decision makers and domain experts. Problem solvers represent the users who need obtain some knowledge to solve a problem. They have some basic and general knowledge about the domain. After problem solving, problem solvers need to describe the process of problem solving as an experience record and store to the experience base for knowledge capitalization. Decision makers are the users who make decision. They can rate the process of the problem solving and its components in order to provide feedback for the problem solvers and domain experts. Domain experts are the users who have the deep knowledge and the necessary experience. Their responsibility lies in the assessment of the problem solving process in order to provide a measure of their quality. They can define the concepts of cognitive situations and chunks of cognitive structures through a knowledge editor.

5 Conclusion

This study makes both theoretical and practical contributions. From the theoretical perspective, this study provides a better understanding of knowledge acquisition at cognitive level. Our problem-driven model for knowledge acquisition captures two important aspects of knowledge acquired in problem solving, that is, the cognitive structures of problem solvers and situations of knowledge acquisition. More important is to introduce knowledge acquisition as a cognitive process, as a spiral of epistemological content that grows upward by transforming tacit knowledge into explicit knowledge, which becomes the basis for a new spiral of knowledge generation. As for its practical implications, our study contributes to the development of an effective methodology for knowledge acquisition during daily work. Our methodology for problem-driven knowledge acquisition can also be applied to enterprise-wide knowledge management practice.

We should note several limitations of our study. Firstly, we assume the relation between cognitive chunks is "or" relation. However in practice, not only the "or" relation but also "and" relation are existed between two cognitive chunks. It is needed to extend the knowledge acquisition model to a multi-type relation model. Secondly, we do not consider the different layers of cognitive chunks. In cognitive psychology, the cognitive structures are layered. So how to model the cognitive structures of problem solvers in layers is very important for the subsequent research. Thirdly, to make the research more accessible and relevant to actual implementation, it is a research topic for future to evaluate knowledge quantitatively and qualitatively based on the proposed model of problem-driven knowledge acquisition.

Acknowledgement. This research is supported by the following research funding: the National Natural Science Foundation of China (71031002, 71501032), and the Social Science Foundation of Ministry of Education of China (14YJC630036, 15YJC630193), respectively.

References

1. Edwards, M.J.: Common knowledge: how companies thrive by sharing what they know. Long Range Plan. **34**, 872 (2001)
2. Robins, S.: Mindreading and tacit knowledge. Cogn. Syst. Res. **28**, 1–11 (2014)
3. Lin, Y.C., Lee, H.Y.: Developing project communities of practice-based knowledge management system in construction. Autom. Constr. **22**, 422–432 (2012)
4. Gebus, S., Leiviskä, K.: Knowledge acquisition for decision support systems on an electronic assembly line. Expert Syst. Appl. **36**, 93–101 (2009)
5. Motta, E.: 25 years of knowledge acquisition. Int. J. Hum. Comput. Stud. **71**, 131–134 (2013)
6. Gruber, T.R.: Nature, nurture, and knowledge acquisition. Int. Hum. Comput. Stud. **71**, 191–194 (2013)
7. Brian, R.G.: Knowledge acquisition: past, present and future. Int. J. Hum. Comput. Stud. **71**, 135–156 (2013)

8. Aussenac-Gilles, N., Gandon, F.: From the knowledge acquisition bottleneck to the knowledge acquisition overflow: a brief French history of knowledge acquisition. Int. J. Hum. Comput. Stud. **71**, 157–165 (2013)
9. Popper, K.: All Life Is Problem Solving. Routledge, London (1999)
10. Breuker, J.: A cognitive science perspective on knowledge acquisition. Int. J. Hum. Comput. Stud. **71**, 177–183 (2013)
11. Chen, Y.-J.: Development of a method for ontology-based empirical knowledge representation and reasoning. Decis. Support Syst. **50**, 1–20 (2010)
12. Jaques, P.A., Seffrin, H., Rubi, G., Morais, F.D., Ghilardi, C., Bittencourt, I.I., Isotani, S.: Rule-based expert systems to support step-by-step guidance in algebraic problem solving: the case of the tutor PAT2Math. Expert Syst. Appl. **40**, 5456–5565 (2013)
13. Kubota, F.I., Rosa, L.C.D.: Identification and conception of cleaner production opportunities with the theory of inventive problem solving. J. Cleaner Prod. **47**, 199–210 (2013)
14. Hao, J.X., Kwok, C.W., Lau, Y.K., Yu, A.Y.: Predicting problem-solving performance with concept maps: an information-theoretic approach. Decis. Support Syst. **48**, 613–621 (2010)
15. Yu, W.D., Yang, J.B., Tseng, J.C.R., Liu, S.J., Wu, J.W.: Proactive problem-solver for construction. Autom. Constr. **19**, 808–816 (2010)
16. Jabrouni, H., Foguem, B.K., Geneste, L., Vaysse, C.: Continuous improvement through knowledge-guided analysis in experience feedback. Eng. Appl. Artif. Intell. **24**, 1419–1431 (2011)
17. Aarikka-Stenroos, L., Jaakkola, E.: Value co-creation in knowledge intensive business services: a dyadic perspective on the joint problem solving process. Ind. Mark. Manag. **41**, 15–26 (2012)
18. Mast, J.D., Lokkerbol, J.: An analysis of the Six Sigma DMAIC method from the perspective of problem solving. Int. J. Prod. Econ. **139**, 604–614 (2012)
19. Wang, Y., Chiew, V.: On the cognitive process of human problem solving. Cogn. Syst. Res. **11**, 81–92 (2010)
20. Reimann, P., Kickmeier-Rust, K., Albert, D.: Problem solving learning environments and assessment: a knowledge space theory approach. Comput. Educ. **64**, 183–193 (2013)