Toward Integration of Knowledge Creation Theories By Primitives Synthesis Through Reflective Verification

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Abstract

In this paper, we present a way to integrate knowledge creation theories by *primitives synthesis*, where we extract basic concepts (i.e. primitives) from several existing knowledge creation and management theories, and combine them into a single framework (i.e. work guide) for analyses of knowledge creation processes in small academic research projects. We apply this work guide to analyze concrete projects in an explorative way and elaborate it through the accumulation of such case studies. We describe a research plan, the extraction of primitives from several knowledge creation theories, the formation of a tentative work guide, relationships between the primitives and the work guide, and excerpts from results of analyses employing the work guide. We conclude that our approach has been successful for integrating knowledge creation theories as a practical framework through reflective verification.

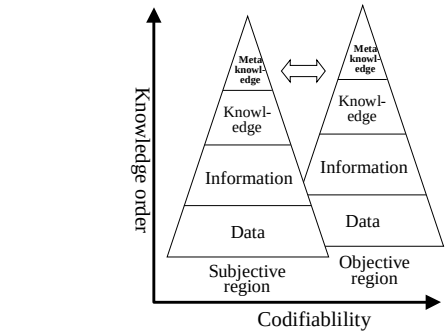
Keywords: primitives synthesis, integration of KC theories, research process analysis

1 Introduction

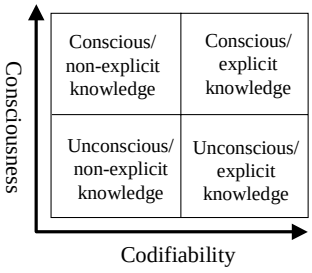
Instead of dealing with models of knowledge creation (KC) on a macro-level, we want to try to underline the use of knowledge management and creation theories for practical use by applying them to the analysis of small-scale research projects in academic settings. Since such projects typically involve few persons and last over longer periods of time, they appear to be especially suitable for an in-depth analysis of knowledge creation processes. Furthermore, scientific work involves logic and reasoning, tacit forms of knowledge [1] and creativity [2] and thus encompasses a wide spectrum of knowledge types and processes. For the analysis, we synthesize existing concepts from knowledge management literature into a single framework (or work guide). The aim of this framework is to identify critical incidents [3] that arose during the course of the project with regards to knowledge creation and use, and to identify supporting and hindering conditions during the course of the project, both with regard to internal and external environment and structure of the project. Ultimately, the analysis of such processes can lead to a knowledge creation model specific to the project. Such models can then serve as a foundation for further successful projects in similar settings.

2 Knowledge and Knowledge Science

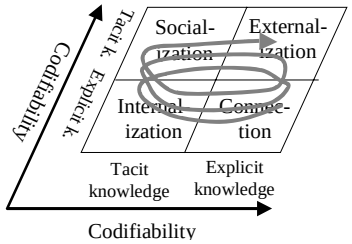
There are no universal concepts on *knowledge* and *knowledge science*. Here we presume the following understanding. Figure 1(a), (b), and (c) show the knowledge hierarchy proposed by Zins[4], the 2D knowledge categorization by Meyer and Sugiyama [5], and the knowledge creation spiral by Nonaka and Takeuchi [6], respectively. Integrating these three concepts, we constitute a *knowledge pyramid* shown in Figure 2. Three dimensions of the knowledge pyramid are *knowledge order*, *codifiability*, and *consciousness*.



(a) Knowledge hierarchy[4]



(b) 2D knowledge categorization[5]



(c) Knowledge creation spiral[6]

Figure 1. Concepts of knowledge

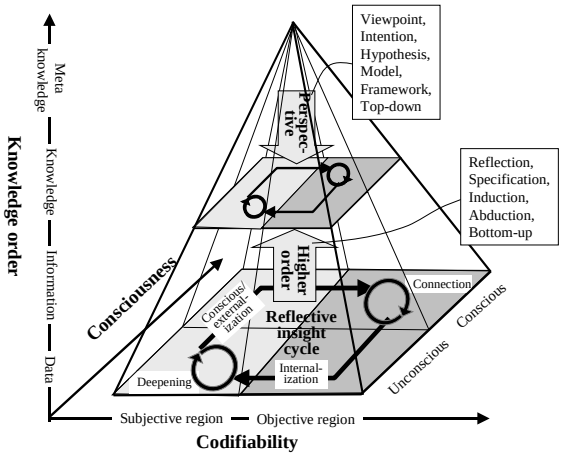


Figure 2. Knowledge pyramid

Data is what is given to an analyzer, researcher, or problem solver and is raw material for *information*. Information is raw material for *knowledge*, and knowledge is raw material for *meta knowledge*. These are called "knowledge in a broad sense". Knowledge in a broad sense is divided into knowledge in subjective and objective (universal) regions [4]. Knowledge can be categorized into four types by implicitness and tacitness [5]. In a knowledge pyramid, knowledge is extended and elaborated through mutual affecting between *perspectiv* and *reflective insight*. A knowledge pyramid expresses a unit of knowledge process. *Knowledge science* is a meta knowledge process to study a knowledge process. Therefore, the pyramid of knowledge science takes a compound structure called a *meta pyramid* shown in Figure 3.

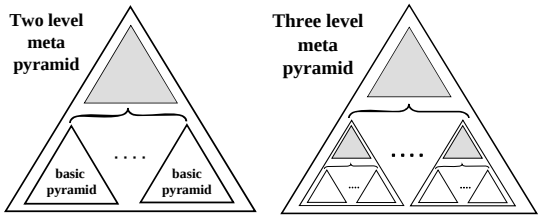


Figure 3. Meta pyramids

3 Our Approach to Integrate KC Theories

Our pragmatic approach to develop a work guide is shown in Figure 4 using the style of a meta pyramid, which is consisted of the following nine steps: (1) extracting primitives from existing KC theories, (2) developing a temporary work guide by trial and error, (3) reviewing own research projects according to the work guide, (4) applying it to other projects in various fields (i.e. cases), (5) improving the work guide based upon experiences for the cases, (6) implementing tools for reviews when the work guide is improved sufficiently, (7) accumulating a lot of cases quickly using the tools, (8) getting insights to improve future projects and education, and (9) obtaining an integrated knowledge creation model finally. In (3), (4), and (7), after the completion of projects, its leader or some project member analyzes their processes precisely. Therefore, this approach is characterized as a *small*, *internal*, *post*, and *knowledge-oriented* analysis [7]. An internal analysis is sometimes subjective but can be precise and clear more than an external analysis.

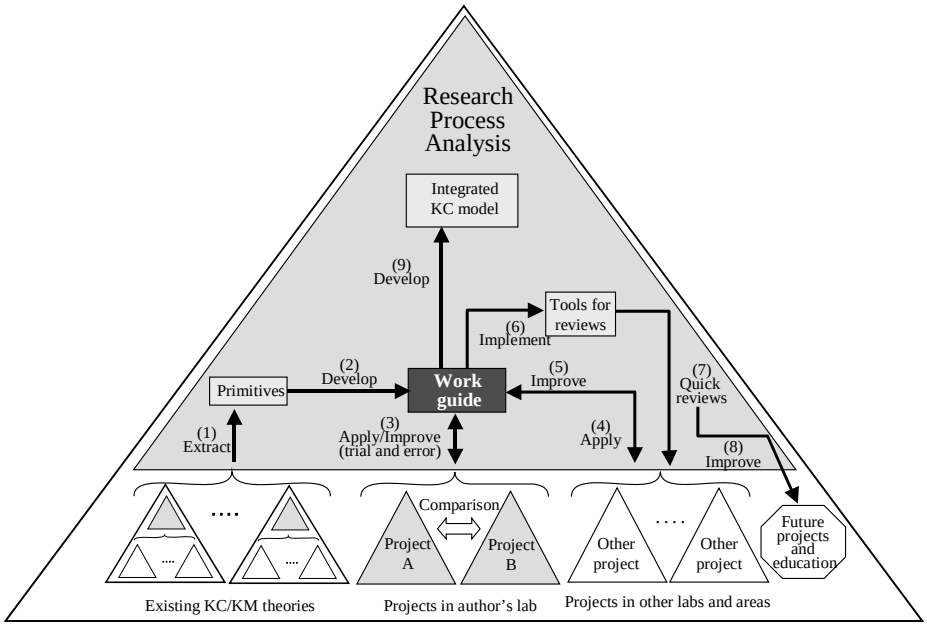


Figure 4. Our research plan for developing a work guide and an integrated KC model

4 Knowledge Creation Theories

In general, a KC theory can explain certain aspects of research activities but not the whole. Therefore, we need to employ several theories for investigating research activities in order to develop a work guide. For the analysis, we focus on the following ideas (please compare original publications in details).

The theory of tacit knowledge: In the book written by Polanyi[1], the author proposes logic of *tacit* thought. The most famous sentence is that "I shall reconsider human knowledge by starting from the fact that *we can know more than we can tell*. This fact seems obvious enough; but it is not easy to say exactly what it means..." He takes as an example knowing a person's face. We usually cannot tell how we recognize a face we know. *Tacit foreknowledge* is one of the most fundamental concepts for the analysis of research processes. Regarding tacit foreknowledge, both aspects are important: what can be seen as a problem, and how it can be seen.

***Equivalent transformation theory*:** Ichikawa[8] proposed a methodology for creative thought called the Equivalent transformation theory. The most fundamental concepts of this theory are *equivalence discovery* and *equivalent transformation*. In his book, he emphasizes that creation is more or less based on these concepts. He also distinguishes two types of routes for the thinking flow: an analog route and a digital route. An analog route is characterized as *intuitive*, *qualitative*, and *imaginary* thought, while a digital route *logical*, *quantitative*, and *real*. Also he states that both routes are indispensable for creation; first, an analog route and then a digital route.

Knowledge creation theory: Nonaka and Takeuchi[6] systematically exploited Polanyi's concept in developing business knowledge, and emphasized the role of the tacit dimension of knowledge in the processes of organizational knowledge creation in Japanese manufacturing companies. The dynamic spiral-type conversions (i.e. *SECI model*) between explicit knowledge and tacit knowledge are convenient analytical framework for knowledge activities in dynamic organization knowledge creation. Besides the SECI model, '*Ba*' (individual and shared context), *knowledge assets*, and *knowledge leadership* are major elements of the theory.

Knowledge process support: Meyer et al [5, 9] tried to link the concepts of individual *implicit*, *explicit* and *tacit* knowledge with findings from memory, cognition and knowledge sciences by developing a two dimensional model of *knowledge categorization*, where *implicitness* (or the degree of consciousness) is one of dimensions and *tacitness* (or degree of codifiability) is the

other. They also proposed basic concepts such as *social network*, *knowledge inventory*, *knowledge exchange* and so on.

Concept Synthesis: In the book written by Finke et al [10], *concept synthesis* is introduced. According to this book, when one makes a new word 'petbird' by connecting two words 'pet' and 'bird', a new property such that 'a petbird can speak' often emerges. Thus, concept synthesis is characterized by the *emergence* of new properties in the mind.

KJ method: Kawakita [11] proposed the KJ method, which is famous in Japan as an effective label-based method for organizing ideas and solving problems. It contains four steps: label making (i.e. *ideas exhaustion*), label grouping and title making (i.e. *multi-stage organizing abduction*), spatial arrangement and chart making (i.e. *knowledge structure mapping*), and explanation.

Serendipity: Roberts [12] pointed out the importance of an *accidental discovery* in science and called it as *serendipity*.

KC THEORY	PRIMITIVE
Tacit dimension *(Polanyi)*	Tacit foreknowing
Equivalent transformation theory *(Ichikawa)*	Equivalent transformation
	Equivalent transformation thinking flow
	Analog route
	Digital route
Knowledge creation theory *(Nonaka et al)*	SECI model (organization dynamics)
	Ba (shared context)
	Knowledge leadership
	Knowledge assets
Non-explicit knowledge process support *(Meyer)*	Social network
	Knowledge categorization
	Knowledge exchange
	Knowledge inventory
Creative cognition *(Finke et al)*	Concept synthesis
KJ method *(Kawakita)*	Ideas exhaustion
	Multi-stage organizing abduction
	Knowledge structure mapping
Serendipity *(Roberts)*	Accidental discovery

Figure 4. KC theories and extracted primitives

Figure 4 shows all primitives selected, where it should be noted that they are mutually independent except two pairs of similar primitives marked in the figure. This might imply that the selection of primitives is successful though it is not based on clear criteria but rather intuitive at moment. We have to make the criteria clearer in the future research.

4 Work Guide and Primitives

Synthesizing the above concepts, knowledge creation through tacit knowledge processes is influenced by the following factors: The course or phases of the project, the social network the actors are embedded into, the individual context of actors, their individual (tacit) knowledge involved, the knowledge exchanges among the actors, the digital and analogue route of problem solving, leading to an overall flow of thinking of all participants. Several of such analyses can be integrated into an overall model of knowledge creation, which can serve as a foundation for other or future projects in the same setting. A proposed work guide composed of nine steps:

1. The progress or course of a project is reviewed along the time axis. A diagram is drawn up to see the overall view of persons involves in the project and the duration of each person's research activity.
2. The social structure of a project and its dynamics are clarified in diagram form. From the diagrams drawn as steps 1 and 2, the phases of a project including SECI modes are identified.
3. The individual context of each member (actor) is remembered and described as a list. Also, the social context of each member is remembered and described as a list.
4. Individual project-relevant knowledge for each member of the research team is assembled as a list based on the dimensional model of knowledge types.
5. Knowledge exchanges among all related persons are identified and assembled as a cross section table.
6. Who can see a problem at first and how he/she can see the problem are identified to clarify an analog route or tacit foreknowledge. Moreover, how this problem is shared among members is also clarified.
7. A research project can be completed only if one can logically bridge a gap between the start and end points of an analog route; i.e. a digital route. Here a digital route is recalled precisely.

8. It is desirable to illustrate both analog and digital routes schematically on the whole as a diagram, from which one can get much information about a project.

9. It is expected that one can develop a newer and more general model for knowledge creation by analyzing a lot of cases and adding primitives.

Step \ Primitive	Tacit foreknowing	E. T. Equation	E. T. thinking flow	Analog route	Digital route	SECI model	Ba (shared context)	Knowledge Leadership	Knowledge assets	Social network	Knowledge exchange	Knowledge type	Knowledge inventory	Concept synthesis	Ideas exhaustion	abduction	organizing	Multi-stage	Structure mapping	Accidental discovery
1. Course of Project	○					○	○	○											○	
2. Social Network and Dynamics						○	○	○		○									○	
3. Individual and Social Contexts	○		○				○	○	○	○		○	○							
4. Individual Knowledge	○							○	○			○	○							
5. Knowledge Exchange								○	○	○	○	○	○						○	
6. Analogue Route	○	○	○	○		○		○						○	○	○			○	○
7. Digital Route		○	○		○	○		○						○	○	○			○	
8. Total Thinking Flow Map	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○			○	○
9. Knowledge Creation Model	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○			○	○
Development and Budget Environment																				

Figure 5. Relations between the primitives and the steps

Relationships between the primitives and the steps are shown in Figure 5, where relationships mean that we can get insights through tasks conducted in each steps.

In the following section, we will report excerpts from an explorative application of a few steps of the above framework within a scientific project as page limitations prevent a display of all findings. The application of the framework is in so far explorative, as issues of objectivity remain largely un-addressed and data collection was conducted ex-post after project completion. This first application should analyze overall practicability of data collection and analysis. Issues of objective data collection and computation will have to be addressed in the future.

5 Explorative Analysis of a Research Project

The framework was applied to a small research project entitled “Creating New Puzzles by Abstraction and Conversion” (See [13,14] for further reference). Its aim was the elaboration of a novel paradigm for user interfaces, with a special emphasis on attractive features that popular toys possessed. For this purpose, we took a systematic approach referred to as abstraction and conversion. The basic idea of the approach is to abstract and convert existing puzzles into other media such as graphs, blocks, sounds, and robots, while preserving their logic. Analysis of operations of the puzzles led to abstract or mathematical models. Based on these models, puzzle generators were implemented and various types of puzzles were produced.

The nine steps of analysis were taken by the supervisor of the project, who subjectively undertook the different assessments. An excerpt of his analyses is outlined in the following section.

5.1 Course of the project and social network

Clarifying the time sequence of the project and the social network among related persons is most important as first step of the analysis since they provide the fundamental axes of a project space. This is done by arranging persons involved and the duration of each person’s activity in a dia-

gram (see Figure 6), identifying project phases and the corresponding modes of the SECI model. In this case, phases identified are: (1) preparation, (2) generation of basic ideas, (3) socialization, (4) formalization, (5) explosion, (6) presentations and publications, and (7) advancement to a new research. Ten persons *A* to *J* in four domestic and one abroad research organizations related to each other: *A* is a PhD candidate supervised by *B*; *B* is a leader of the project; *C*, *D*, and *F* are master students supervised by *B*. Six persons *A*, *B*, *C*, *D*, and *F* are project members. It can be seen that there are two key members *A* and *B*: *A*'s ideas or tacit foreknowledge initiated this project and *B*'s ability for formalization clarified the problem.

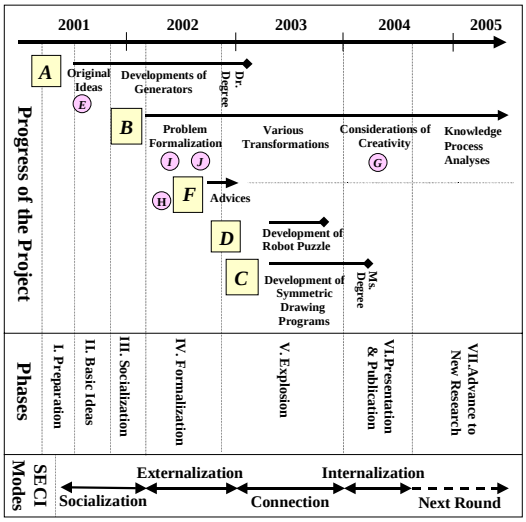


Figure 6. Course of the project: results of Step 1 (Squares mean project members and circles other related persons)

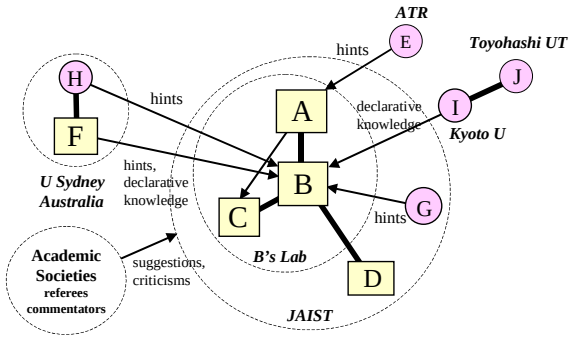


Figure 7. Organizational and knowledge network (results of Step 2 and Step 5)

In Figure 7, the overall social network and knowledge flow among all related persons for the whole project term are presented. Seeing Figure 7, we can recognize the importance of knowledge flows of declarative knowledge and hints from outside professionals: it affected the outcome of the project essentially. This means that keeping a good social network is very important to pursuit research effectively and efficiently.

5.2 Context analysis

According to Nonaka's Ba-theory, context or environment is the most essential factor for a research project. With regard to the contexts, *A*'s individual context seems to be most critical for the project, which can be stated according to eight factors as follows:

Social context: Any revolution or novel paradigm was desired in the research domain of 'user interface'.
Pressure: A had to accomplish his PhD research.
PhD research subject: A's PhD research subject was 'user interface with the engagement effects'. This puzzle research formed a part of his thesis.
Stimulation: *A* was so stimulated when he was on leave to a famous research institute ATR for three months.
Hints: The research topic of 'toy interfaces' was a good hint for his research. It affected him to seek the possibility of interfaces with more logical bases than existing toy interfaces such as 'doll interfaces' and 'miniature gardens'.
Intuition: *A* graduated at an art university and has a good artistic sense.
Skills: *A* has superior programming skills.
Successful experience: In the implementation of the spring layout algorithm used for graph puzzles, *A* had a successful experience.

5.3 Process Map: Analog and Digital Routes

As stated previously, Ichikawa's analog route and Polanyi's tacit foreknowledge are conceptually similar. A tacit foreknowledge (or seeing a problem) is most important for research and is intuitively found by an individual, where a creative mind is indispensable. Ichikawa's digital route (or solving a problem) is logically constructed step by step to find possible routes from the start point to the target point of the analogue route, where experts who have the ability for the coordination and promotion of research are indispensable. The presentation of the digital and analogue route are integrated into a *total thinking flow map* (or process map) of both analog and

digital routes for the project (see Figure 8). In the map, relationships among members, research activities and basic concepts (or primitives) are presented, where we distinguish between equivalent transformations in an analogue route and a digital route and they are denoted as a-ET and d-ET respectively. From the map, we can easily recognize concrete instances (or evidences) of the primitives based on our own experience.

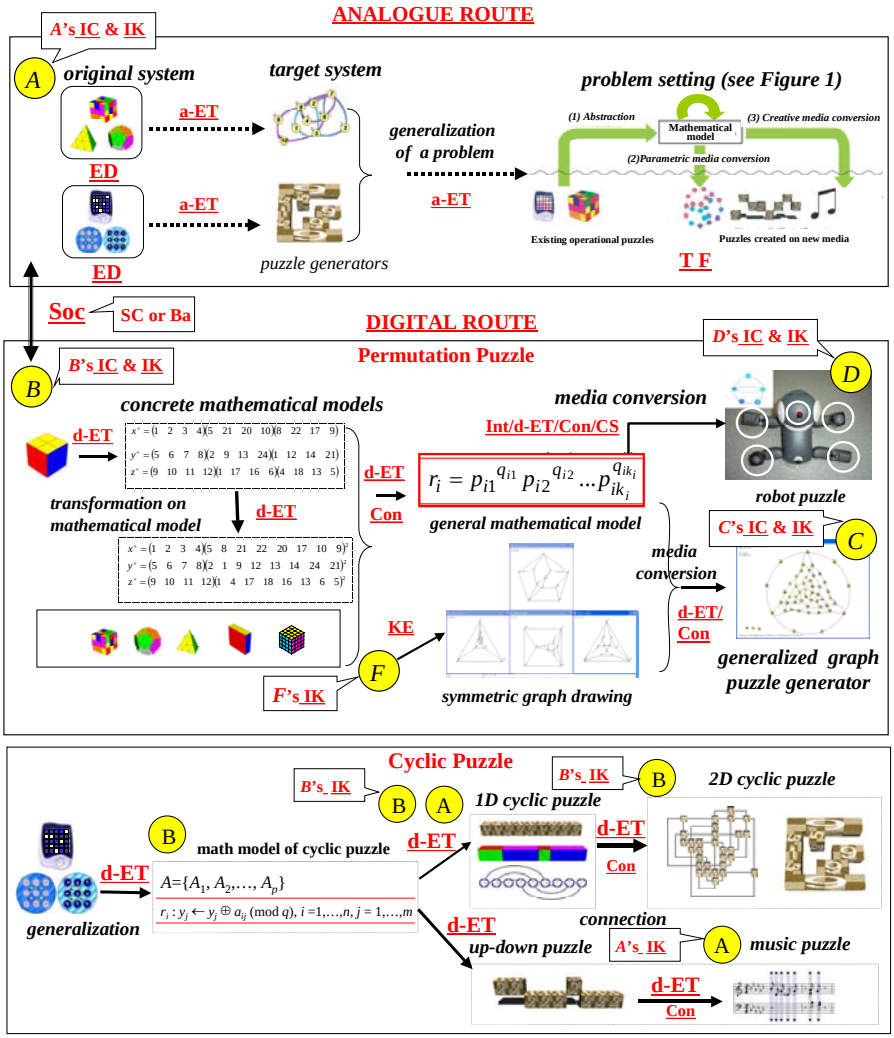


Figure 8. Thinking flow map for the Creating New Puzzles project

(TF: tacit foreknowledge, a-ET: equivalent transformation in analogue route, d-ET: equivalent transformation in digital route, IC: individual context, SC: social context, IK: individual knowledge, Soc: Socialization, Ext: externalization, Con: connection, Int: internalization.)

5.4 Process Summary

From the overall analysis (see [15]), we gain the following insight into the processes of the project:

1. *A* acquired a *tacit foreknowledge* in two steps: In a spec and in a more general way (see left part and right part within the *analog route* in Figure 8). In this stage, *A* did not know how to obtain a mathematical model of puzzles both specifically and generally though *A* had already developed a tentative puzzle generator intuitively.
2. When *A* reported his idea to *B*, *B* assessed it as a

good research problem. This is the only reference to the *socialization* phase of the *SECI model*.

3. After the socialization, *B* formalized and analyzed the problem utilizing mathematical concepts, leading to improved results. In this way, *A* experienced the importance of mathematical analysis for the *digital route*.
4. It is possible to interpret each small *equivalent transformation* in terms of the small-step modes of SECI model: i.e. *externalization*, *connection* and *internalization*.
5. The transformation of abstract models into a robot puzzle can be understood as a *concept synthesis*. The new concept 'Rubik's cube robot'. The new word had power to emerge new puzzles synthesizing two concepts.
6. *Ideas exhaustion* was not enough in this research. We have to challenge further possibility of converging the puzzle into much more other media.
7. Though special strong *serendipity* was not observed in the process of both routes, *A* had a hint for the study of puzzles when he stayed in ATR. This might be week serendipity.

6 Conclusion

A practical work guide for the post-process analysis of small research projects has been proposed and a concrete project was reviewed and evaluated in an explorative way. Results have bee presented in a form of diagrams and tables. Results indicated that it is more than explicit knowledge that contributes to the outcome of a project. For example, individual abilities and skills for foreknowing, formalizing, programming, and coordinating etc. are also essential. Individual and social contexts significantly affect whether a project succeeds or fails. The analysis also reveals potentials for future improvements. We are aware that this work faces issues of subjectivity and arbitrariness. Up to this point, no features are implemented to ensure objectivity of results. These issues have to be addressed in the future, for example in form of guidelines for data recording.

References

[1] Polanyi, M. (1983). *The tacit dimension*. Gloucester.

[2] Simonton, D. K. (2004). Creativity in science : change, logic, genius, and Zeitgeist. Cambridge: Cambridge Univ. Press.

[3] Flanagan, J. C. (1954). The critical incident technique. Psychological Bulletin, 51(4), 327-359.

[4] Zins, C. (2006). Redefining information science: from "information science" to "knowledge science", J. of Documentation, 62(4), 447-461.

[5] Meyer, B. & Sugiyama, K. (2007). The concept of knowledge in KM: a dimensional model. 11(1), 17-36.

[6] Nonaka, I. & Takeuchi, H. (199). The knowledge-creating company: how Japanse companies create the dynamics of innovation. New York: Oxford Univ. Press.

[7] Coghlan, D. & Brannick, T. (2005). Doing action research in your own organization, SAGE Publications.

[8] Ichikawa, K. (1970). The science of creativity. Tokyo: Japan Braodcast Publishing.

[9] Meyer, B. & Spiekermann, S. (2006). SkillMap:dynamic visualization of shared organizational context. In F. Lehner, H. Noesekabel &Kleinshchmidt (Eds.), Multikonferenz Wirtschaftsinformatik 2006 (Vol.2, 528-540). Berlin: GITO.

[10] Finke, R., Ward, T. & Smith, S. (1992). Creative cognition: Theory, Research, and Applications (MIT Press, Cambridge.

[11] Kawakita, J. (1986). The KJ method. Tokyo: Chuo-koron-sha.

[12] Roberts, R. M. (1989). Serendipity: Accidental discoveries in science. John Wiley & Sons.

[13] Sugiyama, K., Hong, S. & Maeda, A. (2004). The pussle layout problem. In G. Liotta (Ed.), Proceedings of GD 2003 – LNCS 2912 (pp. 500-501). Berlin: Springer.

[14] Sugiyama, K. Osawa, R. & Hong, S. (2005). Puzzle generators and symmetric puzzle layout. Paper presented as the Asia-Pacific Symposium on Information Visualization 2005 (APVIS2005), Sydney.

[15] Sugiyama, K. (2007). Post-analysis of knowledge creation processes in small research projects. Int. J. Information Technology and Decision Making. 6(3). (to appear)