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Extenics Based Intelligent Innovation for Creative Education

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Abstract

Under the background that it may be ambiguous to observe the innovation process in a clear way, the study of innovation could be difficult to be modeled. However, the rapid development of IT network paved a way for the research on intelligent innovation. Based on new theories-Extenics and intelligent knowledge management technology, this paper proposed an effective methodology for improving the intelligence in the innovation process. It supplied information and knowledge lacked in the human brains by network information resources, utilized basic-element base platform to break through the limitations of individuals, and used formal methods to generate innovative ideas. This may help to crack the "black box" bottleneck of the innovation process to a certain extent. Its application to creativity education showed a practical significance in acquiring systematic ideas in innovation process and motivating creativity and innovation beyond the information environment.

Keywords: *Extenics, Innovation Methods, Intelligent Innovation, Knowledge Management, Creative Education*

1. INTRODUCTION

It is undeniable that creativity as well as innovation has become more and more crucial for the development of the 21st century. For many years, however, innovation and creativity have been mysterious, and innovation process has been considered as a "black box". Based on current evidence, experience and background knowledge are two indispensable aspects that we take mostly into account in the innovation processes (Satty, 2010). Although today plenty of literatures on innovation are available, there is still a lack of analysis in origins and generative processes of innovation (Birkinshaw, Hamel, 2008). Moreover, the analysis about innovation capability also has insufficient support of quantitative analysis which leads to the limitations of related research fields. This technical barrier greatly impedes the progress of innovation. Several scholars have paid attentions to presenting models of processes (Birkinshaw and Mol, 2006; Cantisani, 2006), but those models don't seem to provide persuading explanation about the micro-level processes of the occurrence of creative ideas.

It's worth noting that today's Internet environment provides an excellent opportunity for innovation. With the development of information technology, especially the World Wide Web and its applications in various fields, such as new social network and media, an increasing amount of information and knowledge springs up in our life, which can be combined with divergent thinking to generate new ideas. However, we found that there was no systematic research on improving divergent thinking capability by information technology.

In fact, the problem lies in the difficulty of generating creative and innovative ideas. Unlike mathematical or physical problems, which can be solved in relatively fixed formula or approach and have a very clear boundary between right and wrong. It's more like an inspiration which we can pick up from our daily life, maybe during the work, study or even while we are walking outside. It's abstract and hard to manage. So, in most situations, the problem should not be blamed on people or the companies, but lies in the dilemma that they cannot figure out a new and creative idea efficiently. Even if they could generate new ideas, the costly attribute may make them reflect on themselves that those ideas may not good or creative enough. Anyway, is there any approach in which the people or company can generate the innovation, or creative idea systematically? There is no doubt that more scientific support is needed in the process of innovation.

2. OBJECTIVES

Innovation is influenced by multiple factors, the basis for creativity is held to involve the production of high-quality, original, and elegant solutions (Besemer and O'Quin, 1999; Christiaans, 2002) to complex, novel, ill-defined, or poorly structured, problems (Mumford and Gustafson, 2007). What allows people to generate high-quality, original, and elegant innovative ideas to solve such complex, novel, ill-defined problems (Tierney and Farmer, 2011; Madjar, Greenberg and Chen, 2011)? Innovation is unlikely to be fully understood simply using a single model. However, creativity can be well understood or explained by a variety of substantive models. Innovation involves multiple, complex processing operations. Effective execution of those processes depends on the knowledge available to the individual and the strategies people employ in executing these processes. The operation of multiple processes, multiple strategies, and multiple knowledge structures makes it difficult, albeit intriguing, to formulate an understandable innovation process (Hennessey and Amabile, 2010; Shi, et al, 2011), so intelligent technology is necessary for improving innovation.

To summarize, the purpose of this paper is to propose an innovation method framework that would support our creative thinking process both theoretically and practically.

3. LITERATURE REVIEW

3.1 Innovation Methods

Innovation involves both the processes and results. We can view it as product innovation, process innovation, business innovation or social innovation (Xu and Nash, 2013). Innovation is an organizational expression of value creation derived from creativity (Bacevice and DeGraf, 2013). Brainstorming is conceivably the best known of all the techniques available for creativity. Brain Storm (Osborn, 1957) makes participants be enlightened by others. But It is not easy to set out systematic procedures for organizing effective brainstorming sessions and evaluating the ideas produced (Rawlinson,1986) under the circumstance that brainstorming mostly rely on experience and knowledge from the perspective of participants themselves. On the other way, the Delphi method develops solutions through a systematic, interactive process between panels of experts which are separated (Linstone and Turoff, 1975). Synectics method (Gordon,1961), which is developed by MIT professor William Gordon, would extract abstract questions from concrete situation and put forward for participants along with the process of discovering the links between different and apparently irrelevant elements (analogy).

"5W2H" (Why, What, Where, When, Who, How, How much), Osborn Checklist method (Osborn, 1957) and Attribute Listing Technique (ALT) take advantage of specifiable questions to enlighten personal thought and decrease pretermission. Checklist method checks for 9 angles,

including other usages, rearrangement, modification, magnification, minification, substitution, adaption, reversal and combination, to generate new ideas and novel solving strategies. ALT would list all the key attributes and breaks the problem down into smaller and smaller bits to figure ways out (Crawford, 1954). As an extension of Attribute Listing, Morphological Analysis (Zwicky, Fritz and Wilson, 1967) is a method for systematically structuring and investigating the total set of relations contained in multi-dimensional, usually non-quantifiable, problem complexes.

As a group creativity technique designed to generate a large number of ideas for the solution of a problem, Six Thinking Hats (de Bono, 1985) combines with the idea of parallel thinking, provides a means for groups to think together more effectively. Other methods or techniques include Lotus Blossom Technique, Ideatoons Blueprint, Neuo-Linguistic Programming Techniques (NLP) etc., Mind Map would be a useful tool for organizing these creative ideas and stimulating more thinking (Buzan, Tony, 1996).

Rickards (1988) and his co-workers (Rickards and Moger,1999) from Manchester Business School examines the theory and practice of systems for creative problem analysis and solving in ways that relate to innovation-seeking systems. Their early work provides a general theoretical model for analyzing innovation generating systems such as brainstorming. A subsequent study examined a system (known as SCIMITAR) which involves systematic examination of a three dimensional structure.

Divergent thinking is another important component of creative thinking and used to generate ideas by exploring many possible thinking directions (Vosburg, 1998). By using divergent thinking, many possible ideas as well as solutions could be explored in a short period of time and unexpected connections will be drawn accordingly. However, divergent thinking typically occurs in a spontaneous, free-flowing manner, many ideas are generated in an emergent cognitive fashion. Therefore, ideas and information need to be organized and structured by convergent thinking after the process of divergent thinking.

There are several activities which promote divergent thinking including creating lists of questions, setting aside time for thinking and meditation, brainstorming, subject mapping / "bubble mapping", creating artwork, and free writing (Hennessey & Amabile, 2010) . But most of these methods rely on individual's experience and thinking ability, for example, in free writing, a person will focus on one particular topic and write non-stop about it for a short period of time, in a stream of consciousness fashion (Edward & Johan, 2000). These methods depend on personal intelligence which would subject to limitations of individuals themselves (He et al. 2016).

Personality traits such as nonconformity, curiosity, willingness to take risks, and persistence also promote divergent thinking in certain ways (Wade and Tavris, 2008). Since it's not realistic to change a person's personality traits within short time, human's divergent thinking capability still relies on experience knowledge or personality traits.

TRIZ is the acronym for "Theory of Inventive Problem Solving" in Russian. The TRIZ methodology was developed between 1946 and 1985 and is now in use world-wide. It is a systematic, left-brain creativity method, and as such, is very well suitable to the development of new and improved products, services, and systems (Hua, et al. 2006). TRIZ research began with the hypothesis that there are universal principles of invention that are the basis for creative innovations that advance technology, and that if these principles could be identified and codified, they could be taught to people to make the process of invention more predictable. TRIZ generates many tools and techniques for innovation. A flow chart is useful when introducing TRIZ, since it shows how the tools are related, as well as what they are. It has been used for either a product design or process development (Ellen Domb, 1997). Further, Li et al (2017) seeks to integrate Extenics with Axiomatic Design Theory.

3.2 Information Technology (IT) Supported Innovation

In the last couple of decades, IT technology has stimulated the development of idea processor (Chen 1999), from earlier example of Axon idea processor (http://web.singnet.com.sg/~axon2000/) to more recent Scamper (http://www.mindtools.com/pages/article/newCT_02.htm), where new

ideas can be generated from interconnection of various concepts, for improvement of products or services. It provides 30 skills and techniques highly creative at work. Invention for artifacts has also been extensively studied (Burke 1978). However, innovations always go behind ideas.

Innovation needs knowledge, Ikujiro Nonaka (1995) saw continuous knowledge creation as the seed of ongoing innovation. He postulated a model of knowledge creation. The model consists of four process, known as SECI, which stands for socialization, externalization, combination, internalization and indicates knowledge conversion created when tacit and explicit knowledge interact.

So basically, the knowledge creation process begins from tacit knowledge, moves to explicit knowledge, and then returns to tacit knowledge again.[1)] Nonaka proposed that successive iterations of the process formed a spiral, in each loop the knowledge was amplified to a higher-level knowledge-creating entity; like the spiral shown in the figure, the process moved from individual to group to organization and then to the community of organization.

Vijay Kumar (2003) proposed a model of the innovation process. He framed it as a two-by-two matrix moving from "hypothesis" to "research", "frame insights", "explore concepts", "make plans" and "implement". He pointed out that "Framing Insights" were primarily about descriptive modelling, creating abstract mental pictures about the patterns that we recognized about reality, and "exploring Concepts" and "Making Plans" were about prescriptive modelling. Where the bridge model forefronts the role of models, Kumar's model forefronts steps that make use of modelling.

Kaiser Permanente's Innovation Centre (working with IDEO) developed this model, in 2004 as part of an innovation toolkit created for usage inside Kaiser. This model is similar to Kumar's model, but the Kaiser model emphasizes storytelling and brainstorming as key methods.

Information and Communication Technology (ICT) tools have experienced tremendous changes in the last decades. Many research trends could be observed that are likely to provide new innovation approaches and effective means to support such new innovation processes (Sorli and Stokic, 2011). In the era of World Wide Web, Information Technology (IT) applied in business has accumulated huge data and information. Knowledge discovered by data mining is novel and quantitative, however, it's difficult to utilize such huge amount of knowledge and information effectively for decision making and benefit the innovation. It is a challenge to look inside the process of innovation based on intelligent knowledge management (Li, Shi and Zhang, 2010).

Intelligent knowledge management (Shi and Li, 2007; Li et al 2009) is one of the new information technologies to support innovation, as *intelligent knowledge* integrates intelligence with patterns discovered from data mining in large databases and utilizes knowledge management technology to accelerate the efficiency of data mining applications. The use of intelligent knowledge from data mining can extend the thinking directions more widely from original data, rough knowledge to intelligent knowledge, and actionable knowledge (Zhang et al 2009) as well as the wisdom (Zeleny, 2006). The practices of intelligent knowledge management remind us to make deeper exploration in the latent process of innovation, for traditional innovation needs new tools and methods (Hippel and Katz, 2002).

4. RESEARCH FORM AND METHODS

Extenics is a new discipline focuses on how to systematically generate creative ideas and solve contradictory problems (Yang and Cai, 2013). After more than 30 years of research, the Extenics scholars have found a set of mature and systematic methods to generate creative ideas or solutions of contradictory problems (Li et al, 2015; Yang, 2017).

4.1 Basic-Element Theory

According to the Extenics, the Basic-element theory defines basic elements of "matter-element" (Physical existence), "affair-element" (events and actions) and "relation-element" for modeling the information (Cai,1990,1994; Yang & Cai, 2013). One dimensional basic-element is an ordered triad, consisting of object, characteristics and corresponding measures, denoted by $R= (N, c, v)$ as matter-element, $I = (d, b, u)$ as event-element and

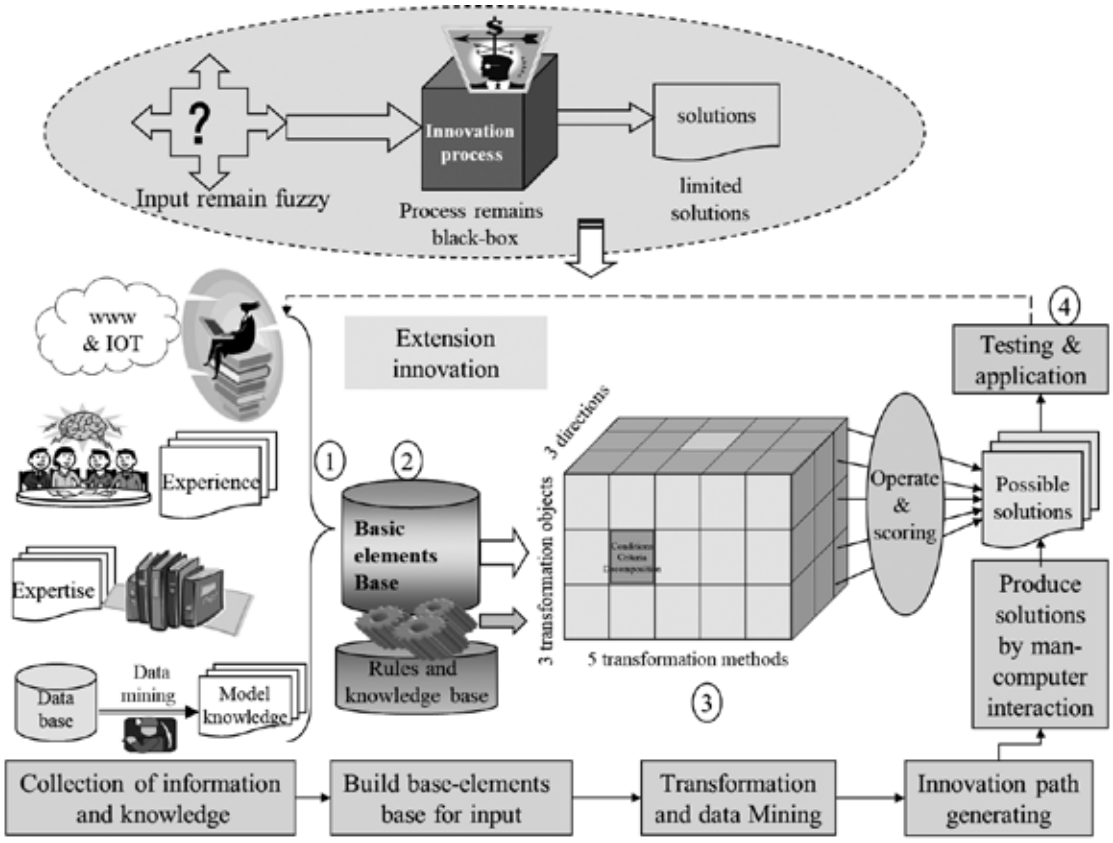

Figure 1: The framework model of Extenics based innovation

relation-element $Q = (s,a,w)$.

The basic-element theory provides formalized languages that can guide us to collect information and think in a systematical way. Changing as time goes by, dynamic matter with multiple characteristics can be expressed as

$$M(t) = \begin{bmatrix} O_m(t), & c_{m1}, & v_{m1}(t) \\ & c_{m2}, & v_{m2}(t) \\ & \text{M} & \text{M} \\ & c_{mn}, & v_{mn}(t) \end{bmatrix} = (O_m(t),\ C_m,\ V_m(t)) \qquad (4.1)$$

As to a given matter, it has corresponding measure value about any characteristic, which is unique at any moment as shown in equation (4.1). The basic-element guide us to think all possible directions in multi-dimensions by using matters' multi-attributes and interactive relations among them.

4.2 Extension Innovation Methods

Extension innovation methods use formal models to discover the extensibility of matters, affairs, and relations, and develop rules and methods to think divergently and systematically, so they are also called Extension Innovation methods (Yang and Cai, 2013; Yang, 2017). They use Extension Set and Extension analysis, conjugate analysis, conversion bridge method, extension transformation matrix and other forms of expression methods to create the novel ideas. In recent years, the application of Extension innovation methods has shown huge potentials and good prospects in many intelligence fields such as recognition, search, diagnostics, data mining, knowledge management, innovation, and strategy generation (Li et al, 2009, 2010, 2014; Liu et al., 2012).

4.2.1 Framework model

Extension innovation methods based on extension theory would take advantage of specific extension methods to generate new innovative ideas or solutions for the problem solving. The framework and its relevant steps are depicted in Figure 1 and are

briefly described as following.

Step 1. Collect information and knowledge
Collect information and knowledge related to the innovation goal^G and practical condition^L from database, expertise, tacit knowledge such as experience and the Web by information technology such as web crawler.

Step 2. Build basic-element base and extensible rule base
Describe and transform the information and knowledge as matter-elements, event-elements or relation-element and save them into database as a basic-element tree structure. Then build extensible rule base and knowledge base to systematically analyse the goal and conditions to generate sub-set of extension information cube by Conjugate Analysis Method. we could get a systematic cube of integrated information (Li et al, 2009).

Step 3. Proceed from chaos to possible solutions by extension cube
According to the goal, condition, or both goal and condition to search feasible propositions by human-computer interactions, we get primary ideas and then score and operate them with operators includes "*And*, *Or*, *Not* and *Xand*", *Xand* means implementing more than two transformations sequentially one after another, where the order cannot be changed.

We then apply 5 basic transformation methods to transform the domain, the elements or the criteria of the goals and conditions.

Step 4. Possible solutions Evaluation and application
We test and evaluate the obtained solutions by *dependent* function method (Yang and Cai, 2013) and determine which solution should be selected, incorporating with experts' suggestions. By operating the primary ideas generated through Step 2 to Step 3 with "*and*, *or*, *not*, *Xand*" and evaluating the solutions, the human-computer interactive process can result in trustworthy innovation proposals.

4.2.2 Methods
The following are description of the methods in detail.

1) Conjugate Analysis Method
Matters possess characteristics of materiality, systematisms, dynamism and antagonism, which are generally called matter's conjugation. According to matters' conjugation, four pairs of concepts have been proposed correspondingly to describe a matter's constitution: imaginary and real, soft and hard, latent and apparent, negative and positive. The four pairs consist of matter-element and relation-element systematically. Its detailed description can be referred in papers and books [6,8].

Conjugate analysis and basic-element theory is a guide for us to think about solutions in a systematic way. Denote physical part as *ph*, non-physical part as *nph*, soft part as *s*, hard part as *h*, apparent part as *a*, latent part as *l*, positive part as *p*, negative part as *n*, Matter-Element as *M*, Event-Element as *E*, and Relation-Element as *R*. Using the notations, for example, *the physical part of relation* can be denoted as R_{ph}.

2) Basic Transformation Methods
There are five basic transformation methods, substituting, adding/removing, enlarging/shrinking, decomposing and duplicating Transformation. Substitute certain object, attribute or value to another one is called Substituting Transformation, adding/removing transformation refers to add or remove certain attributes of the element. enlarge or shrink objects value is called enlarging/shrinking transformation, decompose object, attributes or value is called Decomposing transformation; and Duplicating Transformation means duplicate attributes and its value to similar ones.

3) Extension Innovation Cubes
Basic extension innovation methods consist of 5 dimensions (D in short) as following, every 3 dimensions can form a creative thinking cube to guide us to explore the solutions from multi-dimensions systematically.

D1. Basic-element
According to the Basic-element theory in Extenics, innovation topics can be described as basic elements of "matter-element" (Physical existence), "affair-element" (events and actions) and "relation-element" for modeling the information. One

dimensional basic-element is an ordered triad composed of the element name, the attributes and its values, denoted by $M = (O, c, v)$.

D2. Conjugate analysis and extension analysis
There are four pairs of conjugate parts, from the views of materiality, systematism, dynamic and antithetical natures, that is, the physical part (the entity of a matter's existence) and the non-physical part (the sprit or the space of the element), the soft part (relation structure between parts of a system) and the hard part (each part in a system), the latent part (unnoticeable element or forthcoming change) and the apparent part (noticeable element), and the negative part (the part creating positive value to the goal) and the positive part (the part creating negative value to the goal). Extension analysis includes Divergence analysis, correlation analysis, Implication analysis and extensible analysis.

D3. Innovation directions
Innovation concerns the goals, conditions and the process from conditions to the goals, and the more information we collected, the more helpful to get the goals. There're three directions for innovation, which are goal transformation, condition transformation and simultaneously transform both.

D4. Transforming objects
Based on the theory of extension sets, there are 3 transforming objects include elements (can be described as one or two basic elements), criteria and domain.

D5. Transformation methods
There are five basic transformation methods, Substitution Transformation, Increasing/Decreasing Transformation, Expansion/Contraction Transformation, Decomposition/Combination transformation and Duplication Transformation.

Select 3 dimensions from above 5 Ds, we can get $C_5^3 = 10$ cubes. One of the Extension Innovation cubes below is formed with D3, D4 and D5 as showing in figure 2.

5. FINDINGS

We designed some topics to train creative thinking and innovation based on the above model, and found it is effective and have practical value.

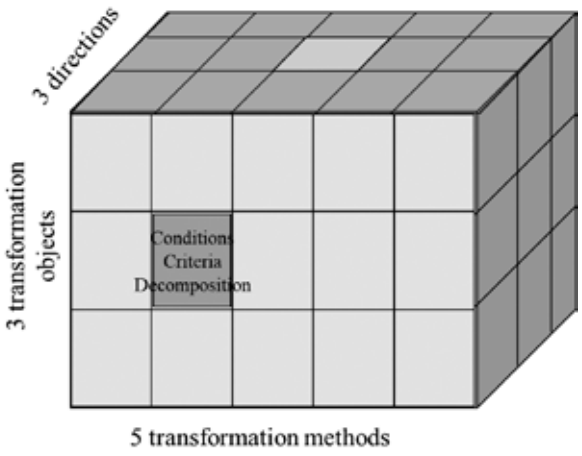

Figure 2: One innovation cube formed with D3, D4 and D5

We designed two questions e.g., "D1. A professor speaks poor Mandarin and his language had no sense of humor, but each of his class was full of students, can you explain it?" Please list as many as reasonable explanations within 10 minutes.

"E2. A college student only got 56 points in his math test, but the tutor was very happy to award him a meal in McDonald's, can you explain it?" Please list as many as reasonable explanations within 10 minutes.

After training by our model, the students increase their reasonable explanations from avg. 9 to 22, and some students listed more than 50 reasonable explanations.

We tested students in 6 groups at the first lesson before our training; most students can only find 3-9 reasons. After 5-week-lesson, we tested students with another question which has the same difficult degree and as many as the same elements.

Lifting degree indicate the improving degree, define D_{old} as the value of the former one, D_{new} as the new one, Lifting degree l denotes as

$$l = (D_{new} - D_{old}) / D_{old} \times 100\%$$

After training, most of them can list out 15-30 reasons. The average Lifting degree is 168.56% of comparison before and after training. Part of reasons the students mentioned is shown in table 1.

Table 1: Part of reasons extended by basic-element model.

Type	Object Name	Attriubtes	Value	Explanation
Matter-element	College student (hereinafter referred to as *He* in short)	age	14	He's only 14 years old and is a supper boy
		Mental health	not normal	He's an unable child, 56 scores are amazing for him
		nationality	Canada	A foreigner
		honest	no	He's honest for the first time and told the parents true score
		ranking	No.1	Total score ranked No.1
		English score	100	He got excellent 100 in English test
	Parents of the student	salary	double	His father is happy for the boss increased his wages
		Lucky events	win	win 5 million lottery (or other bet win), so happy
		history	worse	Parents' achievements even worse when in college
	McDonald	owner	His uncle	His uncle treats all family for opening
		marketing	coupons	Free for students with their parents
		found	surprise	He found McDonald's coupons, to the last day
		future	chance	Get a chance in McDonald's today to win iPhone
Affair-element	Events in life	whom	Obama	Obama met with him
		what	president	He was elected as the president of student union
		Special day	celebration	participate in the National Day celebration
		win	tickets	bet exam 56 scores to win three Olympic tickets
		position	change	just transfer to a new school, different learning contents
		results	win	win 5 million lottery
		date	special	McDonald's day, Free with student ID.
	Exam	score	mistake	Made a mistake, read 56 as 86
		Full marks	60	Full marks is 60 score
		topics	10	He's the only one who solved the most difficult topic among 10
		level	AAA	This test is the most difficult exam
		honor	A	It is International Mathematics Competition
		Last score	40	Made great progress
		time	5.12	After earthquake
		Before events	7:15	He Helped older and delayed the exam
		during	8:30-10:00	He just picked the most difficult topic, disdain to do simple ones.
				There's a earthquake (or shooting) during the exam, he's lucky keep alive
		after	11:30	after the exam he initiative to help others and is praised by the teacher
	dinner	position	White House	They were invited to White House
		date	birthday	His (or of his father, his mother…) birthday (or Wedding anniversary)
			Lucky-day	his father is just promoted and very pleased
			Specical	It's a special day: 1999.12.31
		With who	Movie star	A famous movie star(or Mayor) invited him
Relation-elements	McDonald-Parents	employee	parents	McDonald's hired parents as the manager
		owner	His father	parents successfully bought McDonald shop
	McDonald-Student	attitude	hate	He hates McDonald, so his parents punish him
			love	He will study hard after dinner in McDonald
		customers	Good man	parents wanted him to learn from his excellent classmate, the son of McDonald's manager
	Parents-student	Family status	divorced	Father is happy to meet his son today, once a year
		tendency	good	parents are happy: he went home on time today, did not play games, but learning actively
		Lost status	just found	he lost 2 years ago, just back home yesterday

6. DISCUSSION

Through the theoretical research, this paper found that the lack of innovative methods restricted the improvement of innovation abilities. Over 500 students were benefited from the application of the promotion model of extension innovation in 4 courses such as the course of "the management of information resources". Over 650 students were benefited from Extenics courses and the overall quality promotion courses on this field. Compared with the empirical results, the open innovation ability of the students has been obviously improved, and the innovation program increased 168.56% after the training. By adopting the model to guide students making their resumes and coping with interviews; students' employment rate improved substantially and reached 100% in recent years.

The combination of Extenics and specialized courses would be further studied to realize the innovative ideas or creation of knowledge. By constructing the primitive base with the knowledge of specialized courses, the difficulty level of learning has been reduced. The basic material of expansion and transformation also has been made and creative ideas for problem-solving would be generated in practices.

However, the framework model we presented in the paper is still relatively primitive, the Extenics-based methods need to be integrated to enhance the innovation process. In the era of big data, information and knowledge, more in-depth research on combination of above methods is essential. Moreover, fuzzy set, complexity science and social agent technology will be utilized to improve the innovation model. How to update ontology automatically and simulate the innovation process by intelligent agent is another challenging problem. Integrating intelligent technology with innovation in the era of big data will be our future research directions.

7. IMPLICATIONS

The main features of using Extenics for innovation can be outlined as follows:

Extenics provides a systematic structure for information collection and processing, which can be used as the basis for generation of effective solutions. Due to the completeness of systematic thinking it endorses, Extenics offers an opportunity of capturing important aspects needed for creative and innovative problem solving, which are likely to be ignored by conventional problem solving, or problem solving "by chance".

In addition to generating possible solutions from chaos, Extenics also offers an effective way of evaluate solutions, so that any solutions which failed in the evaluation will be eliminated from further consideration. This can prevent computational explosion.

The Extenics-based approach for innovation can be a human-computer interactive process: Computers can conduct scalable data storage and mining by making use of various algorithms, far superior to human labors can handle. Nevertheless, the real world is extremely complex, and only humans can capture the dynamics of the real world.

8. CONCLUDING OBSERVATIONS

Based on the networking environment, we combine Extenics with Internet information retrieval and intelligent information technology to enhance the capability of individuals on creating new ideas by formalized innovation. The paper reported an effective practical methodology supported by new theory Extensics to improve the intelligence in the innovation process and presents a framework of Extenics-led innovation model and a creative thinking process based on knowledge management and Extenics. It helps us think from 3 paths with 3 directions and 3 objects with 8 aspects Based on the model, we designed guide tables in formularized expression and listed the steps as a thinking tool by 10 innovation cubes. The practices in postgraduates proved its effectiveness.

However, we only used a small part of Extenics. More theories will be applied further to innovation educations, such as extension set theory and extension logic. Due to the significant importance of information and knowledge, the research on combination of extension innovation methods with web information technology, data mining or knowledge management would be further carried out.

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NOTES

1) Michael Polanyi proposed the distinction between tacit and explicit knowledge in 1966.

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