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A Cognitive Perspective on How Experts Develop Conceptual Models in Complex Domains

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ABSTRACT

Conceptual models are important in understanding the domain which is to be reflected in the information systems. Development of such models involves experts in conceptual modeling techniques (ISDK experts) and experts in the domain application (ISAK experts). This paper focuses on understanding how these two types of experts interact and develop conceptual models jointly. Using an exploratory study, it was identified that in the early phase of development of conceptual models, the experts focus on understanding concepts of the domains that they are not familiar with. Later, when the experts had shared information on the concepts of the domains then they focus on developing the conceptual model. The study also indicates that the groups of experts that have high shared information are most likely to create high quality conceptual models.

Keywords

Conceptual model, Cognitive fit, Domain knowledge, Application Knowledge

INTRODUCTION

An important task performed during the initial stages of the development of Information Systems (IS) is called *conceptual modeling* (Hoffer et al., 2007). It involves analysts working with domain experts in some applications to build a representation of the domain called a *conceptual model*. The purpose of the conceptual model is to document features of the domain to be reflected in the IS. Stakeholders such as IS analysts use the models to communicate their understanding of the domain (Wand and Weber, 1993).

Industry initiated conceptual models are now becoming prevalent. For example, to provide a standard description of concepts in the US health industry, the "Public Health Conceptual Data Model" was created (US Department of Health & Human Services, 2000). However, creation of such conceptual models requires application of *IS domain knowledge* or ISDK (i.e. knowledge of representations, methods, techniques, and tools for IS development) and *IS application knowledge* or ISAK (i.e. knowledge of specific applications related to health care) (Khatri et al., 2006). Due to the complexity of the ISDK and ISAK, two different experts are required to develop domain specific conceptual models (Fernandez et al., 2009).

Following is an example of a conceptual model developed jointly by an ISDK expert and an ISAK expert. This conceptual model is developed by using the Extended Entity Relationship Diagram (EERD) technique (Teorey, 1990). EERD is one of the most popular conceptual modeling techniques in practice (Davies, et al., 2006) and it represents concepts such as entities and their relationships of a domain. To apply this technique to a complex domain such as "pharmacology" requires involvement of an ISAK expert –such as a pharmacologist who is familiar with pharmaceutical drugs and an ISDK expert who is familiar with EERD. Together the experts can develop a conceptual model in EERD showing the different functions of a pharmaceutical drug. Part of the conceptual model is shown in Figure 1. Such model cannot be developed by a modeler who lacks knowledge of pharmaceutical drugs concepts or who lacks the knowledge of the conceptual modeling technique (such as EERD).

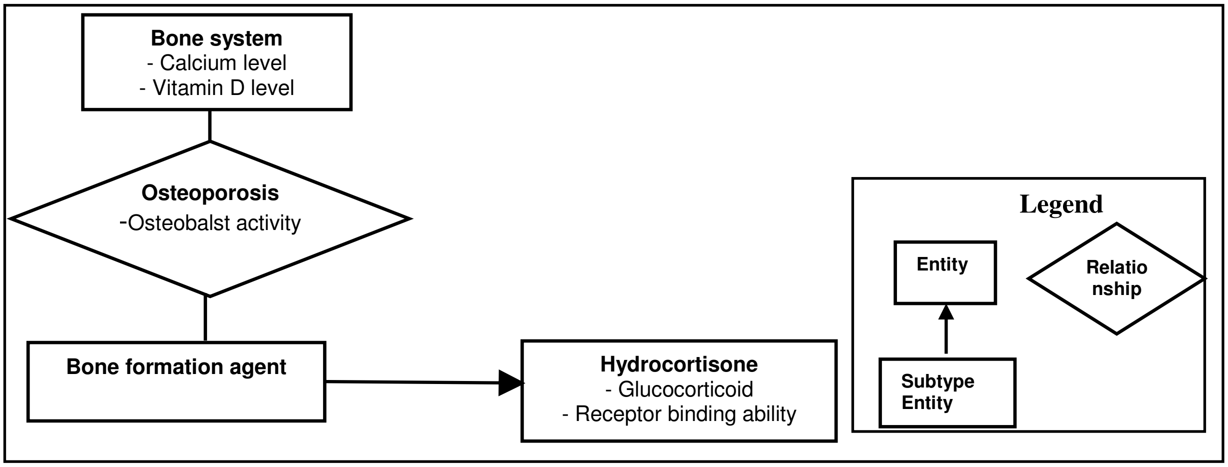

Figure 1: An example of a conceptual model in the pharmacology domain developed by an ISDK expert and an ISAK expert

Although it is widely recognized that communication problems are a major factor in the delay and failure of IS development projects (Curtis et.al. 1988), limited research has been conducted on understanding the communication process among experts in IS development projects (Fernandez et al., 2009). Individual members who are involved in IS development projects often have different backgrounds and typically do not have all the knowledge required for the projects (Walz et.al. 1993). In this context, Fernandez et al. (2009) mention that one important issue in the elicitation process of software development is how experts manage communications especially when they have different and even conflicting viewpoints.

In the context of developing conceptual models in complex domains, ISDK experts have little knowledge of the specific domain application (such as pharmacology) and ISAK experts have little knowledge on the conceptual modeling techniques (such as EERD), thus, a unique situation is created where the two experts interact with each other to develop a conceptual model with very little common understanding - each simultaneously acts as an expert in one domain and novice in the other. Accordingly, the purpose of this exploratory research is to *understand how ISDK experts and ISAK experts interact on creating conceptual models in complex domains.* More specifically, the paper focuses on *understanding the cognitive processes by which these two types of experts create conceptual models in complex domains*.

RELATED STUDIES

Several studies have been conducted in conceptual modeling that focused on how experts and novices create or use conceptual models. Batra and Davis (1992) investigated the performance of experts and novices separately developing conceptual models. They found that experts were able to conceptualize and understand the domain descriptions better than the novices. Shanks (1997) traced the cognitive process of expert and novice data modelers. He found that expert data modelers were better able to conceptualize and understand the case description than novices. In terms of the quality of the models developed by the experts, Shanks (1997) found that the data models are more correct, complete, innovative, flexible, and better understood when built by expert data modelers than compared to those built by novices. Shaft and Vessey (2006) conducted a study to understand the role of cognitive fit in software comprehension and modification. They found that cognitive fit moderates the relationship between comprehension and modification. In particular, changes in software comprehension and modification performance are positively related when cognitive fit exists and negatively related when the fit does not exist. Khatri et al. (2006) examined the effects of both IS and application domain knowledge on different problem solving tasks related to understanding of conceptual models. They found that the effect of IS domain knowledge is important in all types of conceptual model understanding tasks.

However, no studies have been conducted where both experts and novices were involved together in developing or using conceptual models and more precisely, involved experts who act simultaneously as novices.

THEORY AND LITERATURE REVIEW

Understanding the Process of Developing Conceptual Models

To understand how ISDK and ISAK experts develop conceptual models we anchor to the theory of problem solving. Several studies have been conducted where the process of developing or understanding conceptual models were considered as problem solving process (Khatri et al., 2006). Problem solving is a cognitive process where a problem solver finds "a way out of a difficulty, a way around an obstacle, attaining an aim that was not immediately attainable" (Polya, 1968 p. ix).

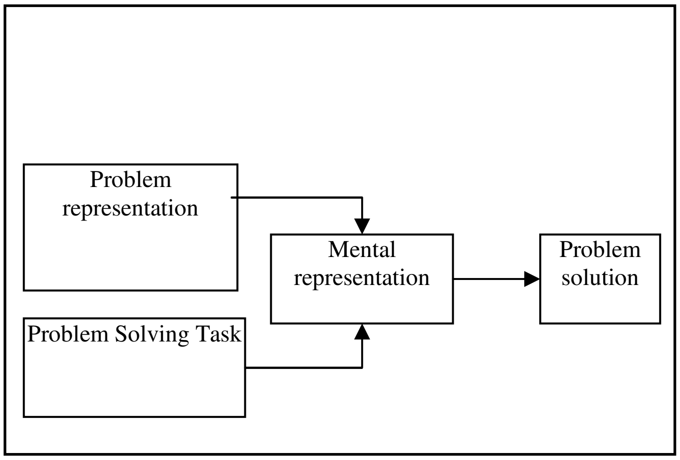

Figure 2 Cognitive fit model for problem solving (Vessey, 1991)

Theory of cognitive fit (Vessey, 1991) can be used to explain the cognitive processes applied by problem solvers in developing conceptual models. In order to solve problems, humans create mental representation of the problem in their working memory and this representation is formulated using the characteristics of both the problem representation and the task (Vessey, 1991). Cognitive fit theory suggests that when individuals need to solve problems in a domain (where "problems" are defined broadly to include complex tasks such as development of conceptual models), their performance will improve if the representation of the problem matches the representation of the domain (Figure 2) (Vessey 1991).

In the context of this research, two specific dimensions of problem solving process needs to be addressed. First, the process involves two distinct tasks- one related to IS and the other related to the application domain that both need to be performed *simultaneously* to develop the conceptual model. Second, the model is developed in a complex domain requiring different expertise thus we investigate the cognitive formulation of each expert (ISDK and ISAK). We discuss these two dimensions in more details next.

<u>Problem solving process involves two tasks</u>

Shaft and Vessey (2006) extended the cognitive fit theory for dual task problem solving. A dual task occurs when problem solvers perform two (or more) tasks simultaneously (Shaft and Vessey, 2006) where each task is referred to as subtask. Shaft and Vessey explain that mental representation of the task solution depends on the mental representations of the subtasks. The mental representation of the application domain is affected by the task of understanding of the application domain and the mental representation of the IS task is affected by the understanding of the IS task (Figure 3). The better the mental representation of the task solution, the better is the performance of the problem solving. In the context of developing conceptual model, the performance of problem solving can be related to the quality of the developed conceptual model. Thus to create high quality conceptual models, it is necessary to have good mental representation of the task solution which in turn depends on the good quality of the mental representations of both application domain and IS task.

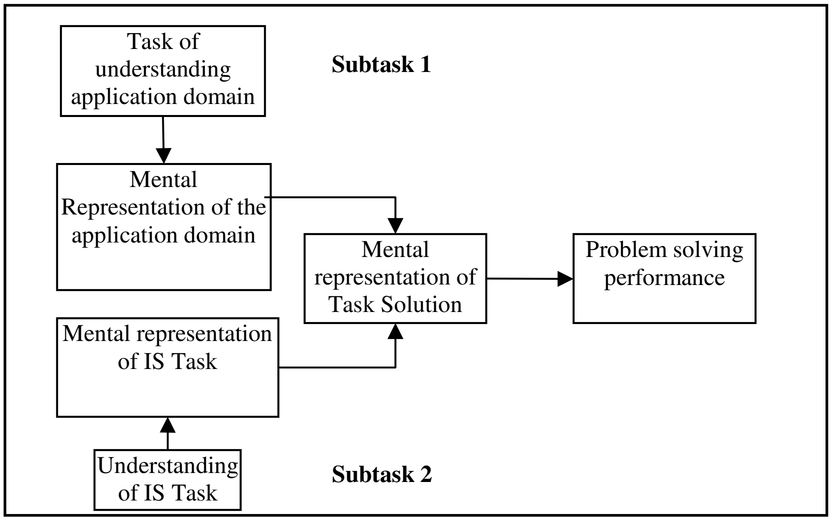

Figure 3: Extended cognitive fit theory for dual tasks (Vessey, 2006)

<u>Mental representations of problem solving experts</u>

As mentioned earlier the type of experts (ISDK and ISAK) who develop these conceptual models are experts in their own domains but novices in the other domains. For example, the ISDK expert might have little or no knowledge about the application domain such as pharmacology and ISAK might have very little or no knowledge on conceptual modeling techniques such as EER. To create a mental representation of a task solution (Figure 3) it is necessary to develop mental representations of *both* subtasks i.e. understanding of application domain and understanding of IS task. In order to form a good mental representation of a subtask, an expert needs to perceive information from external representations and transform it internally (Zhang, 1997). However, if the domain is too complex then this internalization is not possible (Zhang, 1997) and therefore the expert cannot create a good mental representation of the task that he/she is *not* familiar with. Thus in developing conceptual models, each expert will have only a good mental representation of the subtask that he/she has expertise in and a poor mental representation of the subtask that he/she has no expertise in (Figure 4). As the expert needs to integrate the mental representations of both subtasks to create a mental representation of the task solution, the mental representation of the task solution will be of poor quality for each expert (Figure 4). Subsequently, if the experts are asked to develop the models individually, then the models will be of poor quality.

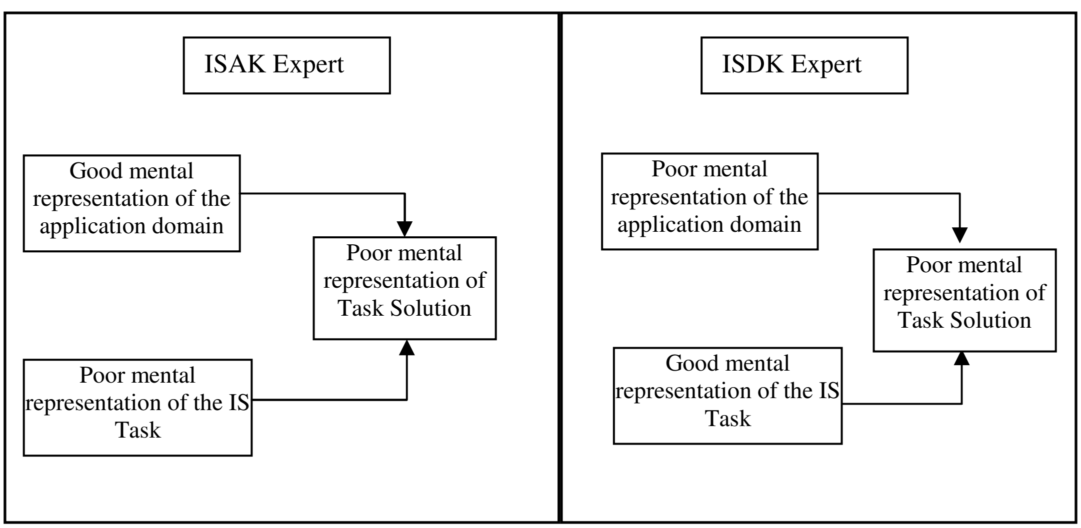

Figure 4: Mental representations of ISAK and ISDK experts while individually solving dual task problems

Propositions

Based on the theory of cognitive fit we now develop propositions related to how experts (ISDK and ISAK) develop conceptual models in complex domains.

Zhang (1998) mentions that it is still possible to do a collaborative task if individuals in a group have incomplete representations of the task. This would be possible if the experts communicate and share their knowledge among them. ISDK expert will teach the ISAK expert about understanding of IS task and ISAK expert will teach the ISDK expert about the application domain. Thus in the early phase of the developing conceptual model, the experts will exchange information about the subtasks. Accordingly we propose that:

During the early stages of developing collaborative conceptual model of a complex domain, the ISDK and ISAK experts will teach each other about the subtasks which they are not familiar with.

When both these experts have sufficient understanding of the two domains *only* then they will have adequate mental representations of application domain and IS task. Once the experts have exchanged information about the subtasks that they were not familiar with initially, each expert will have developed mental representations of both subtasks. Consequently, each expert will have developed mental representations of the task solution. Thus we propose that:

In the later stages of the development of the collaborative conceptual model, the ISDK and ISAK experts will demonstrate evidence that they have developed mental representations of the task solution.

The quality of the task solution will depend on how much information is shared with each other (Kerr and Tindale, 2004). Kameda et al. (1997) refers to the sharing of information as *shared conceptualization* and they predict that if the degree of information exchange is high among problem solvers then these problem solvers perform better. Similarly, Levesque et al. (2001) mention that overlapping cognition which occurs through coordination and communication enhances team performance. Kerr and Tindale (2001) mention that ideas that are shared by group members are most likely to be used in problem solving as no additional justification is needed by the groups to use such ideas. Accordingly we propose that:

The groups where ISDK and ISAK experts have high overlap of shared information will come up with high quality conceptual models.

EXPERIMENTAL STUDY

To gain more on internal validity than external validity, an exploratory laboratory study was designed to test the propositions. The study involved ISAK and ISDK experts developing conceptual models *together* in a laboratory setting. To narrow the scope of the research, a particular conceptual modeling technique -EERD (Teorey, 1990) and a pharmacology domain were used.

Subjects

10 subjects were recruited – 5 were PhD students of pharmacology from a Canadian University and the rest 5 were masters' students in IS from a Southern US University. The masters' students had taken 3 courses (e.g. IS Analysis and Database design) that had components of EERD. The PhD students' thesis topics were related to pharmacology. The average work experience of the pharmacology students was 3 years and that of the master's students was 5 years.

Procedure

5 groups of experts were created by randomly assigning the two types of experts in each group. Prior to the study, experts received a set of background materials to review the domain concepts that they were familiar with.

At the start of the study, a questionnaire was given to identify the expert's familiarity with both domains (pharmacology and EER) (e.g. in Appendix A). Following this, each group of experts was provided with a case description (in Appendix A) and asked to develop a conceptual model (EER diagram) jointly. The experts interacted virtually through a video conferencing software- Adobe Connect. Virtual interaction is quite common in collaborative problem solving (Kerr and Tendale, 2001). Although no time limitation was given but the experts were told that the average time to develop such an EER diagram is roughly 2 hours. This was based on the average time that subjects took to complete similar task in an earlier conceptual modeling study (Shanks, 1997). The experts were encouraged to verbalize their thoughts. The experts' verbalization and their actions on model development were videotaped for analysis. After the study, experts again answered the same questionnaire about their familiarity with the two domains. The experimental materials were developed in consultation with 2 experts (not participants in this study) in pharmacology and conceptual modeling.

Analysis

First we analyzed the protocols of the interactions between the experts in each group. At the initial stages, each expert asked questions to the other expert about the domain which he/she was not familiar with (Table 1). These questions were asked to clarify the concepts until the experts became familiar with the concepts from the other domain.

ISDK expert familiarizing ISA concepts	**ISAK expert familiarizing ISD concepts**
Sample interactions between ISDK expert 1 and ISAK expert 1	
• So, Cortisol binds to the receptor, what is this receptor? • How do you define the immune system? What are the some other characteristics of immune systems?	• What do you mean by *attribute*? • What is the difference between *attributes* and functions?
Sample interactions between ISDK expert 2 and ISAK expert 2	
• Immuno suppressive, can you explain what it is? • What are the characteristics of these systems and how are they different from each other?	• For attributes we need the characteristics of an *entity*?
Sample interactions between ISDK expert 3 and ISAK expert 3	
• I want to find the attributes and just create a relationship like how does hydrocortisone contributes to hyperglycemia • Lowers bone formation. I guess how do you say that	• You mean for each effect, you need to connect to one single *attribute*?
Sample interactions between ISDK expert 4 and ISAK expert 4	
• Is the function of drug in this case, hydrocortisone directly dependent on presentation? • Immune system is composed of cells, what kind of cells?	• OK so what is an *attribute*?
Sample interactions between ISDK expert 5 and ISAK expert 5	
• Can you give me a description to someone who doesn't know any medical knowledge, what is a steroid hormone? • How do you determine when an immune system is over active?	• Can you explain the *relationship* concept?

Table 1: Evidence of experts learning concepts from other domain

In this familiarization process both experts used examples to clarify the concepts. For example, ISDK expert 2 mentioned to ISAK expert 2 (in group 2) that "*entities are basically a concept, an object or a person...Let me give you an example, an entity could be like a person or an account*" Similarly in order to familiarize ISAK concepts to the ISDK experts, ISAK experts provided examples of the concepts about the application domain. For example, ISAK expert 2 mentioned "*Bone system is a structure which gives body shape just like when you build house, we have basic skeleton of the house built with pillars and walls*."

Next we analyzed the group interactions at the late stage of the model development. The experts in each group raised questions or comments using concepts from other domain. This clearly demonstrates that they understood the subtask of the domain that they were not familiar with at the beginning (Table 2). Such comments or questions could not have been made by both types of experts at the early stage of the development of the models. In addition, the experts provided evidence that they were moving towards the mental representation of the task solution. For example, one ISAK expert suggested how the concepts should appear in the model (e.g. "*the three arrows connecting to the human body, those 3 will connect to the cortisol.*")

Evidence that ISDK expert has learnt ISA concepts	Evidence that ISAK expert has learnt ISD concepts
Sample interactions between ISDK expert 1 and ISAK expert 1	
• Can I write *loss of calcium, loss of potassium*, and *calcium level* as attributes of bone system? • What I am trying to model is the different effects of *hydrocortisone* on *bone systems*; especially what are the *diseases* caused by this *drug* on *bones*?	• That should come under bone system, why are you writing it as separate *entity*? • Osteoporosis should *branch out* of the bone system *entity*.
Sample interactions between ISDK expert 2 and ISAK expert 2	
• *Insulin* is a *hormone*. • We can connect *immune system* because it affects the *glucose synthesis system*, right. • Ok, what would be the side effects for the under *active immune system* when cortisol is involved? • Ok, so it reduces the bone density & increase chance of *fracture*, right?	• These *arrows* should be the other way. • The 3 *arrows* connecting to the human body, those 3 will connect to the cortisol. • There should be one *arrow* between the drug & the cortisol because cortisol is one of the drugs. • I am wondering whether there is *connection* between the cortisol and immune system.
Sample interactions between ISDK expert 3 and ISAK expert 3	
• I think, these are specific attributes applied to *overactive* and *underactive immune system* • For *inflammation*, healing time can be an attribute, right?	• Yes, you want to have something like scale, you have to say more or less like level of calcium ion as *attributes* • Instead of the number of allergies, you can write the type of allergic response as *attribute*.
Sample interactions between ISDK expert 4 and ISAK expert 4	
• Suppressing the *immune system*, these functions sometimes can also be sometimes *side effects*, is that correct? • So proliferation of *T-cells* is directly affected by the *Interleukins*	• This is the more descriptive summary of cortisol over bone system, thus decrease in bone density is a better *attribute*. • As an *attribute* it would be increased number of T-cells.
Sample interactions between ISDK expert 5 and ISAK expert 5	
• So there is a conversion of *glycogen* to *glucose* and back to *glucose* to *glycogen*. • Level of *glucose* is stored in liver, muscles and fat tissues	• You could put one *diamond* and then subdivide to one immune suppression system. • You can keep it as Yes/No. You can say glucose transporters not active Yes/No as *attribute*.

Table 2: Evidence that experts learnt concepts from other domain

The communication process was initially driven by the ISDK experts who asked questions on the pharmacology domain. In response, the ISAK experts answered these questions in much detail. If the concepts were not clear to the ISDK experts then the ISAK experts again explained the same concepts in simple terms and by using examples (see above). The process continued until all pharmaceutical concepts were clear to the ISDK expert. Then the ISDK experts initiated the modeling process and explained the modeling technique concepts to the ISAK experts. These concepts were mostly explained using examples. This was followed by the ISAK experts helping the ISDK experts in modeling (such as naming of entities and identifying attributes). Finally, both experts revised the model together to ensure that all the concepts from the case descriptions are covered. It was noted that the ISDK experts asked more number of questions on the pharmacology domain than ISAK experts asked questions on EER concepts. A possible reason could be it was more difficult to learn pharmaceutical concepts than to learn EER concepts

To identify the domain familiarity of experts, each expert answered four questions on each domain before and after the study. The number of correct answers (maximum 8) indicates experts' familiarity with the domain. The average familiarity scores of ISDK and ISAK experts on their own domains were 7.4 and 7.4 respectively (before and after the study). As the scores did not change after the study therefore the experts did not gain familiarity on the domains in which they were already familiar with. However, at the end of the study, experts gained familiarity on the domains that were unfamiliar to them at the beginning of the study (Table 3). In particular, ISDK experts were more familiar with the pharmacology domain than ISAK experts were familiar with the EERD domain. This analysis supports the findings of Table 2.

ISDK Experts	Pharmacology Familiarity		ISAK Experts	EER Familiarity	
	Before study	**After study**		**Before study**	**After study**
ISDK 1	0	4	ISAK 1	1	3
ISDK 2	1	5	ISAK 2	0	5
ISDK 3	0	5	ISAK 3	1	4
ISDK 4	0	3	ISAK 4	0	3
ISDK 5	0	5	ISAK 5	1	5
Average	**0.2**	**4.4**		**0.6**	**4**

Table 3: Evidence of experts gaining familiarity with unfamiliar domains

Next we identified the number of statements where one expert proposed a question or fact and the other agreed on it (e.g. "*For inflammation, healing time can be an attribute, right?*" "*Yes, right*"). We used the number of such statements as indicator of shared information as both experts agreed on such statements. Groups 5 and 2 verbalized 40 and 36 shared statements respectively while the other 3 groups uttered less than 30 shared statements each. Figure 5 shows part of the models developed by group 1 (low sharing of information-22 shared statements) and group 2 (high sharing of information-36 shared statements).

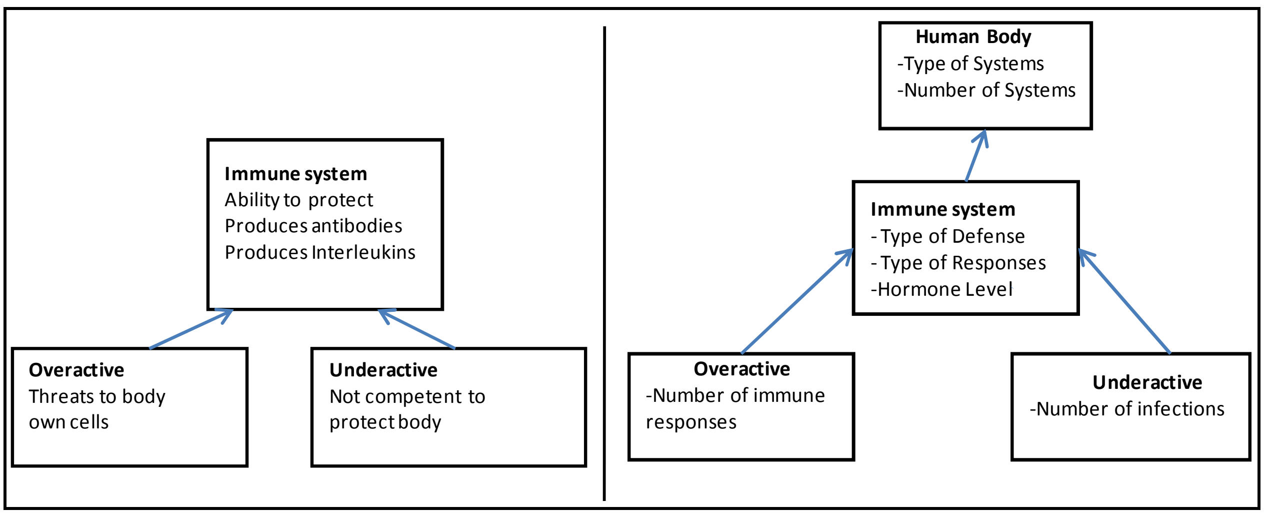

Figure 5: Parts of conceptual models -left side developed by Group 1 (low sharing) and right side developed by Group 2 (high sharing)

The model developed by group 2 can be considered as of higher quality than the model developed by group 1. Note that the EERD developed by Group 1 does not look like a "standard" EERD. A possible reason could be that the experts could not converge to come up with proper names of the attributes.

CONCLUSION

Tasks which require specialized knowledge are more common in many group problem solving tasks (Zhang, 1998). This paper investigated such task of developing conceptual model jointly where the experts had specialized knowledge. The exploratory study identifies that in the early phase of conceptual model development, the experts focus on understanding domains concepts that they are not familiar with. At a later stage, when the experts have shared information on the domains concepts, then they focus on developing the model. The study also indicates that the groups of experts that have high shared information are also likely to create high quality conceptual models. The analysis presented here supports the propositions.

However, further analysis (e.g. correlation between experts' gain in domain familiarity and the level of information shared) is required to further corroborate the propositions.

Several future research studies can be conducted in this area. First, similar studies should be replicated using different domains of varying complexity and different conceptual modeling methods (such as process modeling). Second, in this study, it was observed that shared representations were created at the late stage of model development. Studies can focus on developing mechanisms that can facilitate creation of shared representations of the experts. Third, effects of such mechanisms can be evaluated by comparing the quality of the conceptual models developed (with and without the aid of mechanisms). Fourth, collaborative problem solving among experts often involve conflicts (Sengupta and Te'eni 1993). Studies in this area can focus on how to reduce such conflicts and thus create less cognitive loads on the experts.

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APPENDIX A

Using the following description, prepare an entity relationship diagram *jointly*.

Cortisol is a type of steroid hormone that binds to the glucocorticoid receptor. Cortisol has a pharmaceutical name hydrocortisone. Hydrocortisone is an immunosuppressive and anti-inflammatory drug. Hydrocortisone is available in different forms (such as creams and ointments) and in strengths ranging from 0.5% to 2.5%. Cortisol has both therapeutic use and side effects and thus it affects different body systems in different ways as mentioned next. As Cortisol turns immune activity down therefore it is used to treat diseases that are caused by an overactive immune system. In such cases Cortisol is used to suppress the inflammation. Use of Cortisol on underactive immune system may be fatal. This is because Cortisol - prevents proliferation of T-cells by affecting the interleukin level. Use of Cortisol may cause loss of calcium and potassium. Thus Cortisol has an effect on bone system. It's prolong use might lead to osteoporosis. Cortisol also affects the glucose synthesis system. It counteracts insulin by increasing gluconeogenesis. Thus administration of Cortisol leads to increased circulation of insulin and glucose concentrations in the blood.

Sample questions to assess experts' domain familiarity

1. Which of the following concepts are attributes: Conference, Participant, Name, Integer, Paper_Number, and Percentage_of_Paper_Accepted? (on EER domain)

2. What is the difference between overactive and underactive immune system? (on pharmacology domain)