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A Qualitative Analysis of Expert-Expert Differences in Understanding Aquariums

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Abstract

Research has shown that different kinds of experts within the same domain differ from each other in terms of how they organize and use knowledge. Expertise varies as a function of practice, culture, and goals. Previous research by Hmelo-Silver and Pfeffer (2004) has shown that two kinds of aquarium experts, hobbyists and scientists, have differing mental models of the system. This paper presents a detailed analysis of the experts' interviews to better understand what they choose to talk about and the kinds of reasoning they use. Results show that what experts choose to focus on varies as a function of type of expertise and the goals of different kinds of experts.

Keywords: expertise; expert-expert differences

Introduction

The conceptual reorganization that takes place as a person moves from a novice status to an expert status is well documented (Chi, Feltovich & Glaser, 1981; Glaser & Chi, 1988). The change from novice to expert status involves both quantitative and qualitative changes in the novice's knowledge, and is a function of contextual factors present during the development of expertise. Novices have differing beliefs about what constitutes knowledge and is worth learning, and how it is best understood. These beliefs constrain the type of data that they observe. The empirical data observed in turn helps refine the mental model of the developing expert. Through many iterations of this process, flexible, adaptive expertise develops. Since different types of experts in the same field (e.g. genetic counselors and molecular biologists) have different goals and different kinds of ontological categories, it is reasonable to assume that they pay attention to different types of empirical data. As a result they conceptualize the data differently, and expert-expert differences emerge. Expert–expert differences are a function of goals (Hmelo- Silver, Marathe & Liu, in press; Smith, 1990), culture (Medin et al., 2006) and practice (Patel & Groen, 1991).

Medin et al. (2006) asked expert fishermen from two cultures, Native American and majority culture, to sort a set of fish they were familiar with and to justify their sort. Experts were also questioned about relations between different kinds of fish in nature. The results underscored the importance of knowledge organization. Results showed that both kinds of experts were equally knowledgeable but their classifications differed. The Native- American fishermen lived off the land and had a stake in conserving the natural diversity and harnessing resources in a sustainable manner, therefore their categorization was based on ecological criterion. They also talked about relations between adult and juvenile fish. The majority culture fisherman mostly fished for sport, and sorted fish in categories that were defined by goals (e.g. big fish which are prestigious to catch, fish which are good to eat). Because they usually threw back the juvenile fish, their reasoning about relations among fish was based exclusively on adult fish. The experts' knowledge was task-oriented and organized such that the categories they used most often were most salient.

Chi (2006) defines expertise as, "the manifestation of skills and understanding resulting from the accumulation of a large body of knowledge." (p. 167). Thus expertise is made up of both understanding developed from accumulated knowledge and the ability to use it in some way. Expertise can develop in many ways. One of the salient ways people develop expertise is through formal training (Chi et al., 1981). However, experts are characterized by extensive planning. So expertise consists not only of knowing what to do; but also involves knowing when not to apply the standard procedure to problem solving, as they will not yield the desired result. Dorner and Scholkopf (1991) call this type of expertise "grandmothers know how." This kind of expertise is very important when experts have to control the working of complex causal systems (e.g. maintaining an aquarium, planning an economic policy and implementing it.) It can develop as novices gain informal experience in managing complex systems over a significant duration of time. The practical experience and self-directed learning that people engage in as well as personal mentoring that novices gain from other experts in the domain helps them to become experts. This suggests experts can develop different kinds of expertise in the same domain as a function of their training and practical experience.

Recent research by Hmelo-Silver et al. (in press) found differences within-domains in two complex systems fields. Hmelo-Silver et al. conducted clinical interviews with two kinds of experts, hobbyist and scientists, and novices within the domain of aquarium ecosystem. Analysis of the interviews showed that the two kinds of experts were equally knowledgeable. Experts as a group showed better understanding of the complex system than the novices. The two kinds of experts did not differ with respect to amount of knowledge but did have different mental models of their domain. The hobbyists focused on how to maintain healthy aquaria whereas the mental models of the aquarium scientists were focused on how energy flows across the system and on principles that control ecological systems. This paper is attempts to further analyze the qualitative differences observed between hobbyists and scientists by Hmelo-Silver et al.

Method

Participants and Procedures

Five scientists and five aquarium hobbyists were interviewed as part of a larger study (Hmelo-Silver & Pfeffer, 2004; Hmelo-Silver et al., in press). The hobbyists had gained expertise by reading fish books, going to aquarium society meetings, talking with other hobbyist, and through 10 to 20 years of maintaining aquaria. The scientists had advanced degrees in biology and more than 10 years of experience. The individual interviews ranged from 20 to 40 minutes. All interviews were tape-recorded and transcribed. The participants were presented with a piece of paper that had a three-sided rectangular shape (representing an aquarium). They were asked to draw a picture of "anything you think is in an aquarium," while thinking aloud. The interviews included open-ended questions (e.g., "what is an aquarium?" and "what do we mean when we talk about an aquarium as a system?") and problems (e.g., "What would happen to the aquarium system if the pH went from slightly acidic to slightly alkaline?") to elicit participants' knowledge about their domain.

Parsing

The interviews were parsed into statements for the purposes of coding. Statements were of varying length (they could be part of a sentence or several sentences long) and each was concerned with a particular topic. When the topic of discussion changed (for example, if the participant started talking about role of filters after discussing their positioning in the tank), the unit was parsed as a separate statement. Interview questions, fillers (for example, "umm.., could you repeat that?"), and off topic conversation (for example, the participant talking about how he/she gained expertise) were not coded.

Coding and Analysis

Research in expert-expert differences has shown that knowledge is organized based on how it is used. The categories that are used the most being the most salient (Lynch, Coley & Medin, 2000). We therefore expected to see differences in *what experts chose* to talk about in the domain and also the *way* they reasoned about it. In order to see these differences each statement was coded twice. Firstly we coded for the Focus of the statement, which describes the larger background against which the statement is made. Secondly we coded for the Type of reasoning. Reasoning type describes the way the expert makes connections between the different structures, functions and processes in their domain. The following sections describe the two-level coding and the codes used in greater detail.

Focus of statement: Focus describes the overarching content of a given statement and the background against which it is made. We coded for five different foci (shown in Table 1). These foci were, component, chemical balance, fish, situated system and abstract system. Focus identifies what the expert chooses to talk about. Previous research has shown that experts organize domain knowledge in a goal-oriented manner (Smith, 1990). Since the two kinds of experts used their domain knowledge to achieve different objectives, we expected them to talk about different aspects about the system. We expected the hobbyists, who had hands on experience with maintaining many aquaria, to have detailed knowledge about fish and the components that make up healthy aquaria, and think in terms of the aquarium in particular and not systems in general. Therefore we started out with component focus, fish focus and the situated systems focus. On the other hand because scientific training is based on learning the general underlying principles of a given domain, we expected the scientists to focus on the abstract system view of the aquarium ecosystem. On further analysis of the transcripts we found that these four categories were not sufficient to describe the focus of a large number of statements. Analysis showed that these uncodeable statements were not random and dealt with the chemical aspects of the aquarium. We coded for the chemical balance focus to capture this kind of talk.

Types of reasoning: The type of reasoning in a statement was used to identify how experts understood their domain. Experts made connections between the components of the systems, and the processes that were involved in allowing the system to function optimally. Type of reasoning coded for how an expert made these kinds of connections. We coded for five kinds of reasoning: elaboration, causal, functional, hierarchic, and simple assertions (shown in Table 2).

Experts who maintain complex causal systems possess elaborated knowledge about interactions between different components of the system (Dorner & Scholkopf, 1991). We coded for elaborated reasoning to quantify this kind of in-depth knowledge about aquarium ecosystems. We anticipated that since the hobbyists' primary concern was successfully running and maintaining aquaria they would be more knowledgeable about the day-to day maintenance, and detailed working mechanisms of various components in the aquarium and this would be captured by their greater use of elaborated reasoning. We coded for causal and functional reasoning because research has shown that expert reasoning is causal and functional in nature (Profitt, Coley & Medin, 2000). We expected that the scientists would talk more about the ecological mechanisms underlying the aquarium ecosystem, because scientific training emphasizes the hierarchical and interconnected nature of all systems more than the hobbyists training. In order to capture this kind of talk we included the hierarchic reasoning category. A small number of statements stated facts without any kind of supporting evidence and were coded as assertions.

Table 1: Focus of statement

Focus	Definition	Example
Component	Statement discussed considerations involving physical and biological parts of the aquarium and how they are arranged with respect to each other. These could be the filter, light etc.	"And you would level the gravel bottom, so that there is more gravel on the bottom of the tank…In that way you see the fish up front"
Chemical Balance	Statement either explained various gases, chemicals or chemical wastes dissolved in water in the aquarium system (oxygen, nitrogen etc.), or delineated their effects/ role in the aquarium.	"Carbon dioxide is a by product, … of respiration …But the plants, in turn can reutilize it to produce sugars in photosynthesis and provide themselves with food to grow on."
Fish	Statement was primarily concerned with keeping the aquarium at an optimum level for the fish. It also stressed how a change in the biological, physical or chemical components of the aquarium affected fishes' health in general and in particular.	"...well, the fish might be a little stressed out and not used to the change, so the fish may behave erratic, or their fins might be clammed"
Situated system	Statement is concerned with the function, components, and health of the aquarium system. This is a very integrated systemic view. However it talks about the aquarium system in particular rather than systems or ecosystems in general.	"…you might have some snails that help eat the algae in the tank, and actually there is bright algae that will grow in the tank if you have the light..."
Abstract system	Statement explicitly deals with the aquarium as an ecosystem. The emphasis is on the *system* as a concept and not *aquarium systems* in particular. It does not presuppose that maintaining a healthy aquarium is a prime objective.	"…In a stagnant system in fact you could have lots of life. It's just not the kind that you want for your display,…"

Table 2: Type of reasoning

Type of reasoning	Definition	Example
Assertion	Statement consists of facts without any elaboration or explanation.	"Ok, we'll put the tube light…in the hood."
Elaboration	Statement gives details and non-causal relations between the physical and biological components of the system	"…gravel acts as a bed for nitrifying bacteria to gather."
Causal	Statement refers to how change in some components, actions or processes, affects other components or processes.	"...bacteria breaks down the ammonia and the nitrites fish produce"
Functional	Statement explicitly details why some component or process is important and how it fit in the overall system.	"..the gills of a fish…are meant to take oxygen from water, and the lungs of humans are meant to take oxygen from air…yeah from air."
Hierarchic	Statement explains a chain of causation. These statements are concerned with how a change in one component or process leads to a cascade of events.	"You would immediately see an increase in carbon dioxide and an increase in waste materials, …, after this initial effect, you'd probably see a lag effect …, where the increased carbon dioxide would possibly be taken up by plants, which in fact could generate move oxygen …to come to some new balance in the system."

Coding procedure

Coding was done blind with respect to type of expertise in each condition. One researcher coded all the interviews. An independent second researcher coded 20% of the interviews. Inter-rater reliability was greater than 90% for both type of reasoning and focus of statement.

Results

Since the experts' interviews were of differing length and differed in the number of codeable statements, percentages were used for all comparisons. Percentages were calculated based on the number of times a type of reasoning was used or focus was mentioned divided by the total number of statements that could be coded. This section first presents the results for the focus of statement and then for type of reasoning.

Focus of statement

We expected that the hobbyists would focus more on the component, fish and situated systems view of the aquarium because they developed expertise while maintaining aquaria for over a decade. Similarly we anticipated that the scientists, because of their training, would focus more on the abstract system view of the aquarium system than the hobbyists. In short, type of expertise would interact with type of focus. As shown by table 3, the experts' differing knowledge organization about the aquarium ecosystem was reflected in the focus of their statements. The hobbyists were more focused on the components in an aquarium than the scientists. The scientists focused more on the abstract system view of the aquarium. Even when specifically asked about a component of the aquarium system, namely light, the focus of a scientist was on the general/ abstract systemic nature of the aquarium as in this example when he said, "Light is essential in the ecological sense of the system in that it provides for the photosynthesis by the plants."

The results of ANOVA show a significant interaction between focus and the type of expertise ($F(1,4) = 7.86$, $p<.001$). The hobbyists' statements had component focus reliably more than those of scientists ($F(1,8) = 6.87$, $p< .05$). The scientists used abstract system focus more than the hobbyists ($F(1,8) = 50.62$, $p< .001$). We also expected the hobbyists' interview to have more statements that focused on the situated system focus and fish than the scientists. While this was the case, the differences were not statistically significant.

Experts were, however, flexible in how they viewed the aquarium ecosystem. Though the hobbyists focused mostly on the component view of the aquarium they could change gears when asked to do so. The hobbyists were capable of thinking of the aquarium as an abstract system or ecosystem. When specifically asked about the aquarium as a system, one hobbyist said,

> An aquarium as a system…implies the life cycle of…fish consuming food, which produces waste, which feeds the nitrifying bacteria, which then feeds the plants, which produce oxygen, which provides oxygen for the fish so…

This answer suggests that the hobbyist could think of the aquarium as a system, in a general sense. He did not talk about components of the aquarium when specifically asked about its systemic nature. Therefore, while the component focus was salient for the hobbyists, they could demonstrate broader understanding when the task demands required it.

Similarly the scientists could also focus on the components of the aquarium in particular and not think of the aquarium as a general system, as can be seen from the following statement made by a scientist concerning placement of light in the aquarium, "…we'll put a tube light on top, because light is important. It's in the hood."

Table 3: Descriptive statistics for focus of statement

Focus	Scientists (n = 5) Mean (S.D.)	Hobbyists (n =5) Mean (S.D.)
Component*	24.93 (4.45)	37.42 (9.67)
Chemical balance	8.11 (2.50)	8.82 (4.21)
Fish	16.55 (5.69)	25.36 (8.35)
Situated system	16.67 (13.94)	21.24 (10.38)
Abstract system**	33.75 (7.58)	7.15 (3.52)

* $p<.05$ ** $p<.001$

Type of reasoning

We expected the scientists to reason more hierarchically because scientific training emphasizes the hierarchic nature of systems. The hobbyists had significant hands-on knowledge of maintaining aquaria. They were therefore more likely to know about the various components of the aquarium in greater detail and to use elaborations more than the scientists. However as can be seen from table 4, while the differences were in the direction predicted they were not significant. We conducted a set of orthogonal within subject contrasts. The results showed that both scientists and hobbyists used elaborated, causal, functional and hierarchic reasoning more than simple assertions. The results were statistically significant for hobbyist at $p< .01$ ($F(1,4) = 17.46$) and for scientists at $p< .001$ (F 1,4)= 92.12). It is possible that the type reasoning is a function of expertise in general and not related to type of expertise.

Table 4: Descriptive statistics for type of reasoning

Type of reasoning	Scientists (n = 5) Mean (S.D.)	Hobbyists (n =5) Mean (S.D.)
Assertion	6.79 (3.08)	9.09 (5.84)
Elaboration	40.01 (6.97)	48.11 (11.79)
Causal	23.26 (11.21)	18.22 (10.93)
Functional	27.05 (10.18)	22.84 (8.04)
Hierarchic	2.90 (1.64)	1.73 (1.17)

Discussion

The results of this study show that there are considerable differences between how hobbyists and scientists understand aquariums. The scientists focused on the aquarium as an abstract system that approximates an ecosystem. The hobbyists' focus was more practical as they emphasized the components that comprise the aquarium system, and how they affect each other.

The results from this study are in keeping with prior research that has shown that practice in applying knowledge to solve problems has a very big effect on what facets of the knowledge are used in a privileged manner (Patel & Groen, 1991; Wineburg, 1998). This differential focus on local and global issues underlying a complex system, by two kinds of experts is similar to what Barnett and Koslowski (2000) demonstrated in another domain. They showed that management consultants were better able to provide solutions for systemic problems (i.e., problems created by location, peoples' intentions and changes in highways routes) facing a restaurant than the restaurant managers responsible for its day-to-day running. This was true even when the consultants were not very knowledgeable about restaurants in particular. They proposed that this pattern of results is likely given the fact that restaurant managers are very busy in making sure that the restaurant functions smoothly. Their cognitive resources are used up in thinking about everyday problems of running a complex system (i.e. the restaurant). They cannot spare any resources to look at the "big picture." The results of this study show a similar pattern with the hobbyists focusing more on components while the scientists take a more abstract view of their domain and focus on the big picture.

The higher levels of organization are those that help people apply their knowledge to the task at hand (Eylon & Reif, 1984). The hobbyists' domain knowledge about the aquarium system was acquired through trying to maintain numerous aquaria over a long period of time, as well as through informal learning opportunities. It is not surprising then that their knowledge is organized around the aquarium. While hobbyists can think about an aquarium as an ecosystem approximation, they do not necessarily think about it as such, unless specifically asked. However, they do have the domain knowledge to think more flexibly when needed. Similarly the scientists' knowledge is organized around the scientific principles that govern the system. They can think and reason about the practicalities of running an aquarium but, they do not do so unless specifically asked., as other expert-expert studies have demonstrated (Lynch et al, 2000; Medin et al, 2006).

Most expert-novice studies focus on mostly scientific experts. Since these experts acquire domain knowledge within the culture of academia, they focus on the underlying principles governing the domain (Chi et al, 1981). However this type of principle centered knowledge organization may not be characteristic of all kinds of experts. Generalizing the characteristics observed in formally-trained scientific experts, to all kinds of adaptive experts, may not be appropriate under all circumstances. Scientific and non-scientific experts organize knowledge differently. This difference in knowledge organization is seen between molecular biologists and genetic counselors (Smith, 1990), between taxonomists and landscapers (Lynch et al., 2000), and between scientists and hobbyists in the present study. Evidence from these studies suggests that the pattern of classifying according to underlying principle may be characteristic of expertise of only a certain type, that of scientists and academicians. Researchers use basic principles in the domain to design experiments and their knowledge is therefore organized around these principles. Other kinds of experts (e.g. genetic counselors, landscapers, aquarium hobbyists, respiratory therapists) use their domain knowledge to solve practical problems. Their knowledge is organized around solution techniques and so their classification differs from that of scientists. The present study also shows that while experts have their privileged categories, these categories are not rigid. The experts can be flexible when needed in response to situational demands, consistent with Lynch et al.

We did not see any difference in the kinds of reasoning experts' use across the type of expertise within the aquarium system. Thus while types of reasoning might be useful to distinguish between experts and novices they might not be very useful to differentiate between different kinds of within-domain expertise. It is also possible that greater differences were not observed because the expert interviews were conducted to elucidate expert-novice differences and may not have been ideal for studying expert-expert differences. More application questions requiring hierarchic answers might have resulted in more hierarchic reasoning and resulted in better differentiation of expert-expert differences in this domain. The experts were also asked specifically about components of the aquarium during the course of the interview. This might have cued the experts to talk about them. In the absence of these direct questions it is possible that experts might have talked about certain aspects of the systems differentially; and their knowledge about other aspects of the system might have remained unarticulated and implicit. Thus showing greater differences in what they choose to focus on.

Another limitation of this study is the small sample size. The small sample size makes it difficult to find statistically significant differences between the two kinds of experts. The limitations of the interview structure and sample size not withstanding, significant differences were observed between experts in what they chose to focus on.

Conclusion

This study demonstrates that expert-expert differences exist in the domain of aquarium ecosystem. Results indicate that these differences are of a qualitative nature and knowledge organization is a function of how knowledge is applied and used by the experts. The two kinds of experts have in-depth knowledge of their domain and are able to reason about it in a sophisticated manner. They use predominantly elaborated, causal and functional reasoning. However further research needs to be done to understand precisely the effect that goals and practice have on development of expertise within complex domains.

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