

Features of High School Students' Components of Conceptual Ecologies

HyunJu Park*

Chosun University

Abstract: The purpose of this study is to explore the relationship between selected components of conceptual ecology that are reflected in high school science students' statements, when answering questions. This study follows from a position that there is reason to believe that, in the process of answering questions, many aspects of conceptual ecology are likely to play a role. Data were gathered through six audio-taped interviews, the science teacher's profiles of each student, the students' personal journals, their assignments, and their examinations and participation in class. Kay and KY were selected as the focus of this study because theirs were both dramatic as well as representative cases. As the findings suggest, learning styles differ according to distinctions within individuals' conceptual ecologies. Thus the way in which a person learns science varies according to the construction of her/his conceptual ecology. This suggests that different forms of pedagogy may be effective with different types of learners. This also suggests that science educators may have a role in assisting students to develop into constructed, rather than received, learners.

Key words: conceptual change, conceptual ecology, learning style, science

I . Introduction

The constructivist perspective has given rise to important models of learning, such as the conceptual change model(CCM), which was posed by Posner, Strike, Hewson and Gertzog(1982). The CCM is based on the assumption that individuals rationally construct their own knowledge in order to interpret phenomena. Posner *et al.*(1982) borrowed their epistemological perspective of knowledge revision from the fields of the history and philosophy of science(Kuhn, 1970; Lakatos, 1978; Toulmin, 1972). The theory of conceptual change became the leading paradigm that guided research and instructional practices in the science education community for many years(Ault, Novak, & Gowin, 1984; Duit, 1999). However, it also became subject to criticism that it views learning as purely a rational process that lacks attention to psychological aspects such as affective aspects and motivational constructs in students' learning (Damastes, Good, & Peebles, 1995; Duit & Treagust, 2003; Pintrich, Max, & Boyle, 1993; Vosniadou & Ioannides, 1998).

The CCM focuses on the epistemological reasons conceptions change status in the conceptual ecology of an individual. While this is an important dimension to conceptual change, others have criticized it as too narrowly focused on rationality and view the CCM as a vast devaluation of the complexity and diversity of the issues *vis-á-vis* conceptual change learning(Disessa, 2002). This needs serious consideration. Within the CCM, two important elements in the model of conceptual change are: (1) the status the individual learner attaches to competing conceptions and (2) the individual's conceptual ecology in which the conception is incorporated(Hewson, Beeth, & Thorley, 1998; Hewson & Lemberger, 2000). Conceptual ecology provides a context for understanding individuals' conceptual change learning, as it is the environment in which all information is interpreted(Hewson, 1981, 1982; Hewson & Hennessey, 1992; Posner *et al.*, 1982). Conceptual ecology helps individuals find the deeper structures and commonalities in the world, that then allows them to reason causally about the observations they make, and to create

*Corresponding author: HyunJu Park (hjapark@chosun.ac.kr)

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knowledge that incorporates and changes conceptions (Hewson & Lemberger, 2000). Conceptual ecology includes not only cold, rational, epistemological reasoning, but non-rational elements that may affect the status of conceptions such as the variety of different types and psychological aspects of knowledge held by individuals. Each of these "types" influences the learning of new knowledge (Davis, 2001; Deniz *et al.*, 2008; Hewson, 1984, 1985; Johnson & Southerland, 2002; Posner *et al.*, 1982; Strike & Posner, 1985, 1992; Thorley, 1990).

All the components of an individual's conceptual ecology have developmental histories and that these histories cannot be understood apart from their relationships with other components in the learner's conceptual ecology (Strike & Posner, 1992). Components of conceptual ecology, then, interact and build on one another.

When describing relationships between elements of conceptual ecology, this paper views human relationships described by Hinds (1996) as a useful analogy. Hinds distinguishes between relationship and interaction, with the overall relationship consisting of any number of interactions, and being defined by the nature of those interactions. Interactions suggested by Hinds include reciprocal, complementary, and conflicting interactions. Using Hinds categorization as an analogy, identical interactions between components of the conceptual ecology that have the same effect on each other either simultaneously or alternately define reciprocal interactions. Different but enhancing interactions between components of the conceptual ecology define complementary interactions. Conflicting interactions diminish the influence of one or the other of the components involved in the interaction.

A person's conceptual ecology contributes to determining the status of a conception, the conditions necessary for conceptual change, and the processes of conceptual change. As Toulmin (1972) stated, the degree of the status of

a conception within its conceptual ecology affects the influence it has on intellectual selection. The development of one's intellectual disciplines creates a diversity of approaches limited only by selective influence of active conceptual problems (Johnson & Southerland, 2002). Hewson (1981), and Hewson & Lemberger (2000) provided detailed case studies of how elements of individuals' conceptual ecologies influenced the status of conceptions leading to conceptual change in an individual, and individuals working in groups. Key elements of their conceptual ecologies that affected status were anomalies, analogies, metaphysical beliefs, the power and promise of an idea for solving a problem (fruitfulness), and consistency with other high status knowledge. The study described in Hewson & Lemberger (2000) was done in a problem-solving classroom where students worked from effect (data resulting from fruit fly crosses) to cause (conceptual models of genetic inheritance built by the students). The problem-solving structure of this classroom along with questions the teacher posed to the students during the problem-solving process forced the students to activate elements of their conceptual ecologies to build and justify their conceptual models of inheritance.

This study explores some aspects of conceptual ecology that provide a context for understanding individuals' conceptual-change learning. The strength and nature of the components of an individual's conceptual ecology can have an impact on a learner's conceptual change experience. Some researchers have investigated the interactions or relationships of various components of conceptual ecology. Hewson (1985), for example, showed the relationship of epistemological commitments and metaphysical beliefs to students' conceptions with evidence that showed internal consistency and generalizability. Roth and Roychoudhury (1994) reported the importance of students' understanding of the nature of knowledge, the nature of learning, and epistemological

commitments. Beeth(1993) examined the existence of the components of conceptual ecology in students' statements and concluded that specific components of those conceptual ecologies influenced the students' understanding of a conception.

By using the lens of conceptual ecology to explore components of an individual's conceptual ecology, and the relationship between components, science educators will gain a richer understanding of the nature of the learner. If a student's conceptual ecology differs from that of other students, a teacher may decide to modify teaching strategies to account for that difference. At a deeper level we may also ask whether it is possible to add elements to a lesson that move learners to a stronger epistemological stance. Most of all we must undertake research that explores how differences in conceptual ecologies affect the process of conceptual change learning in science and responding to science questions. Research on personal conceptual ecology has the potential, for example, to open up a line of thinking about learners' conceptual ecologies, thus suggesting new lines of science education research to develop foundations for future applications, of teaching strategies and curricula.

The purpose of this study is to explore the relationship between components of conceptual ecology reflected in high school science students' statements, made in answering questions. Other research make little connection between the nature of knowledge, the nature of learning and the affective domain(self-esteem and/or self-image), nor these components with other components of conceptual ecology. What we have tried to do in this research is to understand who the learner is by exploring the components of that person's conceptual ecology, and by positing and examining the inter-relationships between these components. This study follows from a position that there is reason to believe that, in the process of answering questions, many aspects of conceptual ecology are likely to

play a role(Chan & Bereiter, 1992; Chan, Bereiter, & Burtis, 1993; Lemberger, 1995). This research addresses conceptual ecology as a totality and does not focus on changes in any components of students' conceptual ecologies. The specific question to be addressed in this research is: What, if any, are the relationships between components of two high school students'conceptual ecologies?

II. Research Methods

Design and Procedure

To investigate the features of high school students' components of conceptual ecologies, a case study approach was employed(Creswell, 1998). Purposeful sampling determined the students who would act as informants for this study. This research implied two types of triangulation: data and investigator.

A collective case study of two high school students was employed. The individual cases were bounded by time, just prior to, during and just after a four week science unit entitled, "Processes Fundamental to Living Organisms: Obtaining Matter and Energy." The students' conceptual ecologies were the objects of the study. We were seeking to understand components of individuals'conceptual ecologies, and the relationships between these components, thus in depth data from a variety of sources was appropriate(Creswell, 1998; Lloyd-Jones, 2003; Strauss & Corbin, 1990). The multiple sources of data gathered provided the necessary depth of data for each case(Merriam, 1998). This provided multiple opportunities for ideas to re-occur and/or contradict themselves as the different components of the conceptual ecology were being identified. This included the coding of data with components of conceptual ecology, using the multiple data sources for support and contradiction of emerging themes about each case.

Participants

This study began with seven sophomore high school students, aged 15–16 years old. Two cases were selected for this study. Kay and KY were selected because theirs were telling cases. Such cases may be more fruitful in developing meaning than a typical case (Ellen, 1984). Patton (1990) labels the selection of such a telling case, one type of purposeful sampling, as an extreme or deviant case, “This approach focuses on cases that are rich in information because they are unusual or special in some way. Unusual or special cases may be particularly troublesome or especially enlightening.” (p.169) Since epistemological commitment is an important part of one’s conceptual ecology, Kay and KY were selected because they represented extremes in Belenky’s *et al.* (1986) domain-general epistemological categories.

Kay was selected because she represented a case whose domain-general epistemology was classified as a received learner. KY was chosen because he was classified as constructed learner. KY’s conceptual ecology fits Belenky’s *et al.* notion of a constructed learner who experiences himself as a center of learning and who values both subjective and objective thinking. As a constructed learner, KY believed that all knowledge is dynamic and that he is an intimate part of his learning. Kay, on the other hand, is best described as a received learner *vis-à-vis* Belenky’s *et al.*’s work. She relied on received knowledge that comes from authorities. In addition, Kay thought of words as central to the learning process and thus did much of her learning by listening.

One should recall that Belenky *et al.* (1986) categorized the different types of learners based mostly on the nature of learning, and self-esteem. This research attempts to understand who the learner is by exploring the components of that person’s conceptual ecology, and by positing and examining the inter-relationships between these components. Since the notion of

conceptual ecology provides a context for understanding an individual’s learning in terms of the environment in which all information is interpreted, conceptual ecology includes such components as epistemological commitments, metaphysical beliefs, and past experience as well as the nature of knowledge, the nature of learning, and the affective domain.

All participants were volunteers and none required special services. The principal of the high school and the science teacher agreed to allow this study to take place in Ms. Won’s science classroom on the condition that students give their own approval and obtained that of their parents for participation in this research. The content domain for this study centered on the natural phenomenon of leaves changing color and falling off trees, that was a four-week unit in the science class offered to high school sophomores. The unit included not only the question of leaves changing colors and falling from trees, but also conceptions that were related to this natural phenomenon, such as photosynthesis, energy, and plants structure and function. The content domain of the research has the additional advantage of being tangible phenomena. Individuals construct intuitive conceptions of natural phenomena based on their empirical experiences and prior knowledge (Driver & Erickson, 1983; Osborne & Freyberg, 1985; Posner *et al.*, 1982). In other words, students have their own conceptions they have developed intuitively to explain their world.

Data Collection

Data for this study were collected during six interviews in which two students took part. The data also include the science teacher’s profiles of each student, the students’ personal journals, their assignments, and their examinations and answers in class.

Open-ended, one-on-one interviews were used to characterize components of conceptual ecology. Each interview consisted of a set

preplanned questions and follow-up probes. Driver et al. (1985) was the primary source for the construction of interview questions. The interview was piloted and revised for intelligibility and face validity. Each student has six interviews that were scheduled at the convenience of the student. All interviews took place at the high school, and were conducted by one of the researchers.

In the first and the second interviews, conducted before the instruction of the unit began, for getting a general idea of what the individual student's conceptual ecology might be, the students were asked what they thought about when they heard the name of the season 'fall.' In the third and the fourth interviews, which were conducted while the students were studying the unit, the goal was to see what the roles of components of their conceptual ecologies were when we showed the students anomalous data. We also wanted to see how the students justified their answers to the questions. The anomalous data concerned the autumnal process of white oak trees whose leaves turn brown but remain on the tree until the next spring. Once again, we asked follow-up questions based on their responses. The questions were asked in order to get an idea of how the students justified their answers. For example: "Why do you believe that?" "How do you know that is true?" "Why did you say that?" "Where did you get that idea from?" In the fifth and the sixth interviews, we also asked the students what their views were of a problem, how they solved problems, and how they validated a piece of information. We then asked follow-up questions based on the responses they had given to the interviewer. The questions were once asked in order and designed to detect students' conceptions of a problem and of science: "What is a problem?" "How do you try to solve a problem?" "How do you know your problem is resolved?" "How do you know your answer is right?" "What is science and what is not science?"

Other documents we collected from the class

included: research notebooks, assignments, quizzes and exams, and a profile of the students written by the teacher. The two students kept a laboratory notebook where they wrote ideas and thoughts, reported the results of their experiments, and answered some questions. Assignments provided a way for the students to reflect on their ideas and/or problem solving and served as a means by which we could see how they reasoned while forming answers to the questions. Questions for reflection were posed by the teacher. Quizzes and exams provided an avenue to ask how problem solutions could be justified. The two students' profiles written by the science teacher gave us a general idea about each student's background, personality, and attitude toward science.

Data Analysis

This study is primarily descriptive in nature. The findings considered are those that bear directly on the task at hand: An analysis of selected components of the students' conceptual ecologies and interpreting the relationship between components of the conceptual ecology that may point to a pattern in these components. The interviews were taped, and transcribed by the researcher. Transcripts were coded using the components of conceptual ecology as defined by Park (1995). Each component was individually analyzed into categories of responses. Then patterns across components and categories of conceptual ecology were looked for in order to find themes in the students' thinking. The transcripts of interviews were also examined with an eye toward identifying evidence that a student is thinking about her conceptions, rather than only with them.

This paper explores the feature of high school students' conceptual ecology with their related conceptions about knowledge, the nature of science, and learning. These are important because one's conceptions about knowledge, metaphysical beliefs, and learning are important

contributors to one's conception of learning science.

Three colleagues who have been studying as doctoral students in the field of science education and have been working science teachers in high school were asked whether or not they agreed with the analysis of the data. Each one was to read a transcript of a student who participated in this study. They were also asked to read the interpretation of the data, and later, to report to the researcher about whether they agreed with the analysis. All three concurred with interpretation of the two students' conceptual ecologies.

III. Results

This research presents evidence for a claim this study makes about the features of conceptual ecology: There are different types of learners based on different conceptual ecologies (Park, 2007). The evidence for this claim appears below in a discussion concerning the research question of the study which is: What, if any, are the inter-relationships between selected components of conceptual ecology?

The results present a portrait of two students, KY and Kay, in order to understand the inter-relationships in the components of their

Table 1
Conceptual Ecology Profiles of KY and Kay

Components	KY	Kay
Epistemological commitments: I believe it's true because...	<ul style="list-style-type: none"> - it comes from an authority and also makes sense to me. - it is commensurate with other knowledge. - I have observed it. 	<ul style="list-style-type: none"> - it comes from an authority. - many people believe so.
Metaphysical beliefs: some leaves are yellow and other red because...		<ul style="list-style-type: none"> - tree wants to... - it's just happens...
Affective domain & emotional aspects: I...	<ul style="list-style-type: none"> - like science. - am curious about science stuff. - don't think this unit is important to learn because the science teacher didn't spend much time on it. 	<ul style="list-style-type: none"> - hate science. - am not good at science.
The nature of knowledge: Knowledge...	<ul style="list-style-type: none"> - comes from authority but can be evaluated by me. - is dynamic. 	<ul style="list-style-type: none"> - comes from authority.
The nature of learning: A piece of knowledge is acquired through...	<ul style="list-style-type: none"> - understanding and application of the piece of knowledge, i.e., problem solving. 	<ul style="list-style-type: none"> - memorizing the piece of knowledge.
Past experience: I've had...	<ul style="list-style-type: none"> - a lot experience of non-formal, informal, and formal science activities. 	<ul style="list-style-type: none"> - most experience in formal science instruction.
Problem solving strategies: *A problem is... *I am *I believe a problem is solved if...	<ul style="list-style-type: none"> *some situation that I am trying to get to in the future. *trying to find a solution by following my own reason of how to find it. *the problem doesn't stop me again. - there may not be a solution to the problem. 	<ul style="list-style-type: none"> *assigned by a science teacher or in the text book. *trying to find what a teacher or a text book, or other students think is this solution. *the solution is the same as the teacher or what another student has, or is in the book.

conceptual ecologies. In so doing, the results give a more human face to the discussion and show how the various components of conceptual ecology interact and overlap. KY's case will be described first and this will then be followed by a focus on Kay. A brief comparative discussion of the two students concludes this session.

Case 1: KY

KY was a unique student in that he was the only freshman enrolled in the sophomore program, having skipped most of the ninth-grade science course. According to KY's science teacher, this was a rare occurrence in the high school. Early on in the year the science teacher was asked to accept KY into the sophomore program even though he was a freshman. Because of his age, size, and unique abilities, however, KY had problems feeling comfortable in his new class. At first he answered many questions posed by the teacher or by the material in a unit, but gradually (in science as well as in several other subjects) he moved out of the spotlight. In a conference the science teacher had with his mother, the latter expressed concern that KY was beginning his growth spurt and his interest, attitude, and effort seemed to vary from one minute to the next. His good recall capability seemed to be "getting him by" occasionally but he no longer sat at the top of the class. In spite of these changes, KY still came up with insightful answers when most of the students were unable to address a question, thus showing the promise and interest that had advanced him to the sophomore class in the first place. KY always sat in the first row in the center of the classroom. When he took a short test, he stayed long after the bell rang indicating the end of the class. He was very quiet, but questioned the teacher if something did not make sense to him. For example, he asked, "Where does the chlorophyll go when the leaves change color?" When the discussion focused on developing a leaf model, KY's model was a

bowl-shaped leaf that he thought would hold more water. The front of his leaf was waxy which, he argued, functioned as a protector from physical things, sunlight, and water loss. KY demonstrated his understanding of how a leaf gets water by comparing leaf cells to the absorbent properties of a sponge. KY defined science as three things: "a thinking process, an image, and a way of life." He added later:

Science can be thought of as a way of life, our life. We rely on science, technology, and especially on science for everything. ... [Science] will tell you to approach things logically. Science is also the thinking process of taking things one step at a time and only changing one variable at a time. This is science because it is the path that scientists follow to reach a conclusion. ... My favorite example of 'not-science' is fortune telling. It is not based on any logical premises. ... Other things that are not science are like just assumptions, like guessing without testing, and religion and sports.

Epistemological commitments

Inferences can be drawn from many of KY's statements in the interviews, that have bearing on his epistemological commitments—how he justified his belief that a piece of knowledge was true, and how he justified his reasoning while answering a question. KY validated knowledge in a domain-general context by relying on omniscient authority, such as a teacher, but his own evaluation also played an important role in his justification of why something struck him as being true. In the domain of science when he answered how the earth was created, for example, KY said, "*a really, really long time ago, a bunch of swirling gases and dust and stuff, all clumped together deformed the earth that we're on...*," and added, "*because I've seen a little tiny thing rolling around underneath the bed on a hardwood floor, and get much bigger, and turn*

into a big dust ball.” KY switched from authority to personal or empirical experience.

However, when KY was probed as to how the earth was created in a way that produced changes from season to season, he displayed the “push and pull” of official versus his own thinking on the subject:

...their [scientists'] goal is to find out how everything is created. They've come up with this big long story. But, I don't believe, I don't believe all their answers, because I don't know how it would happen that a tiny little organism over a long, long period of time would turn into a human, you know, through many generations, its offspring ultimately could become humans.

KY justified knowledge through authority, but also through his own observations, and/or the consistency that a piece of knowledge had with other knowledge. KY's understanding of a sphere, for example, came from his understanding of the mathematical definition. Thus when he explained how we get different seasons and different weather, he stated:

The earth is tilted a little bit, which is another puzzling thing to me. Because they also say the earth is a sphere. Tilted is kind of a vague term when you're talking about a sphere. Because a sphere would be, uh ... well, a mathematical definition is all points in equal distance away from one point. That's you know, roughly, approximately true when you consider the size of the earth and then the size of mountains, and then like, if it's really equal distance all the way around, it's going to be perfectly, like symmetrical in all ways, so how can it be tilted because then it's symmetrical in another way...

KY followed this explanation with what he thinks the science experts would offer by way of explanation:

The earth tilts and then the sun's rays strike it, strike the earth, at, at a different angle and for some reason that means, that means it makes it hotter in some places and colder in others.

When KY was asked what his own idea of the seasons and of weather change was, and if that of the scientists' explanations made sense to him, he commented, “Well, I guess I'm going to have to say that mine is the science people's answer. Because I still haven't decided, I still haven't decided what my answer is going to be yet.”

KY was confident in his potential to be a constructed learner even in the face of his tendencies to accord teachers and scientists high status as validators of knowledge. Although he commented “I would have to assume that they [science teachers] are right, because I've never been told anything contradictory to what they have said,” he was also aware that there was dissent and controversy even among the “experts.” When KY elaborated upon his idea of the creation of the earth, for example, he began his explanation by saying, “Let's see, the latest thing I heard, seems to me that they [scientists] change this [the idea of how the earth was created] on a regular basis.” KY's awareness of shifting or contradictory opinions within the world of official science boosted his confidence in his capacity to arrive at answers other than those of authorities. One can infer that KY felt free to question authority.

Affective domain and emotional aspects

KY seemed comfortable challenging his own answers to the questions offered by the interviewer. His enthusiasm for science was the central feature of his affective domain and emotional aspects. Scientific study outside the classroom had complemented his formal school training, as KY had a childhood in the natural beauty of rural area. As he noted:

I know I've always been real curious about things, especially things that I couldn't explain just by looking at... and just like, gave explanations that I suppose I could believe, or a lot of things going on around me, and it got me more interested and then I learned more, and got more questions about what I learned and got more interested.

KY, however, was also like many of his peers in the credence he gave to authority, especially when it came to judging the importance of a piece of knowledge on the basis of how much weight it received in the science curriculum at school. Thus, even though he is a constructed learner and likes science, KY was also concerned about grades and school, which led to his conclusion that *"because this has been taught over and over in science,"* it must be important. Conversely, the less something was repeated, the less significant it must be. As KY commented, *"we might not need to know this [leaves changing color and falling off trees] because she said it once and she hasn't brought it back up in the last week."* This shows that KY had a pragmatic response to the learning task, which suggests that given the situation of learning science in school, it was rational for him to think that if a teacher spent little time on a unit, then it was unlikely to be on a test. Therefore, it was alright not to study this unit.

Past experience

KY revealed that he has a strong interest in a variety of activities related to scientific learning which included formal science classes in school, the less formal but nonetheless structured setting of a science camp, and finally the informal process of engaging in scientific discovery by him. As he noted:

I've done a lot of science type stuff, a couple of camps, many years of science and ...that one statement [regarding leaves

changing color] is like, all my science so far compiled into one statement.

With such a variety of experiences KY had much in the personal realm upon which he could count when it came to scientific reasoning and observation. He had learned much from *"Just what I've noticed while I've been alive. Just what I've noticed and read about. What I've noticed, would be my experience in, what I've learned from."*

KY was quick to refer both to the classroom and to his own pursuits when justifying why he felt a certain aspect of knowledge to be true, bringing up his science teacher and a television show called "The Real Jurassic Park" in a single sentence. Again, however, he did not rely on official authorities alone, taking much enjoyment and intellectual satisfaction from his more spontaneous activities: "I do a lot on my computer in programming and other types of things," he commented.

And a lot of time just when I get a great idea, I go try it. And sometimes things happen and sometimes it's just... I just have great ideas sitting around for a while.

Clearly KY's sensory observation and past experience played a significant role in his understanding of leaves changing color and falling off trees, as he indicated when he referred once to his rural upbringing which took place before his family moved to Madison: *"I used to live up in Door County, and there were a lot of parks... that's just how I know that this appears to be like autumn, and spring and summer."* In KY's case, both sensory observation and the affective domain had a direct impact on how he regarded the process of learning science.

The nature of learning & knowledge

In terms of his affective domain and emotional aspects, KY manifested a strong link between

learning, curiosity and interests. For KY learning was not confined to memorization but was much more a building-block process of understanding and application. KY regarded learning as *"Taking a piece of knowledge or a bit of information and remembering it or, understanding it so that it can be used... comes in handy or something, um, um, like remembering something well enough to be able to apply it."* To learn a piece of knowledge, according to KY, requires understanding and applying it, otherwise it will be lost.

For KY one difficulty in the nature of learning is that gaps can occur between the time a piece of knowledge is learned and used:

I forget a lot of things that I don't use...If I don't use a piece of knowledge, I forget it after, after a short period of time.... They don't do it intentionally, it just happens that if you're not using a specific piece of knowledge, you just after a while can't bring it back into memory anymore, you can't say it, or express it.

KY made statements that indicated his notion that scientific knowledge was often produced by scientists, and was composed, to some extent, of facts to be memorized. KY understood the process whereby officially sanctioned knowledge was produced:

Because either directly or indirectly I think we get most of our knowledge from the scientists. They figure something out and they publish it, and then it's put into textbooks from the universities, and eventually we learn it from them. That makes sense to me.

KY recognized that scientific knowledge is produced by scientists, but was also aware that knowledge is dynamic, as he commented, *"Let's see, the latest thing I heard, seems to me that they [scientists] change this [the idea of how the*

earth was created] on a regular basis." One can infer that KY's confidence might result in him understanding how scientific knowledge is dynamic, convincing him that learning came through rote memorization.

KY also made statements that indicated he believed knowledge was constructed from personal experience. He commented, *"I've done a lot of science type stuff, you know. A couple of camps, many years of science and that's, that one statement is like, all my sciences so far compiled into one statement. I made it up myself."*

Problem-solving strategies

KY defined the answer to a problem as *"something that's completing a goal" and a problem itself as something that "keeps them from completing a goal, and some situation that you are trying to get to in the future."* For KY, there are several contingencies to be considered in problem solving. First, he might not place his first loyalties in an authority's definition of the process or in an official source of knowledge. As he explained it:

It seems like I continue going, if I can continue going toward whatever goal I was working for at the time, and I started ahead and if the problem doesn't stop me again, I'm going to guess that it's solved.

Second, for KY, not only might an answer not be the same as what an authority had expected, he might not find an answer at all. In such a case he will temporarily resort to the official answer, but will reserve the right to determine his own answer later: *"I'm going to have to say that mine is the science people's answer. Because I still haven't decided what my answer is going to be yet."*

Discussion of KY

KY believes knowledge comes from authority but is aware that scientific knowledge is

dynamic. He understands that knowledge and learning are constructed from his personal experiences. He sees that learning is both a process of understanding and application of scientific knowledge to some situation, i.e., problem solving. He experiences himself as a center of learning and values both subjective and objective thinking. KY has the idea that science is about curiosity and discovery. In this regard, it is reasonable to describe him as a constructed learner.

For KY, there is a strong link between learning and curiosity. He seems fairly confident in his abilities in science, and this contributes to his occasional questioning of authority, and to his relative independence as a thinker.

Much of KY's confidence springs from his understanding of the nature of learning in which he sees himself as a center of learning and regards learning itself as a building-block process of understanding and application. Additionally, KY's view of the nature of knowledge in which experts are responsible for producing knowledge that could then change or undergo revisions also lends this student a sense of confidence. Further interaction of the themes of conceptual ecology were evidenced in KY's epistemological commitments in which we saw his evaluation of knowledge mingling with his affective domain. This means that KY's occasional skepticism about knowledge springs quite often from his confidence in himself. KY's sense of self-esteem in the realm of scientific knowledge is in evidence, for example, when he stated, "*Depends on, you know, if I thought it [a science fact] was true, I would expect a scientist to say it was true. And if I said it was false, I would expect a scientist to say it was false.*" KY's enjoyment of science is directly linked to his confidence, to his ability to reason, and to past experience in general. His healthy sense of self-esteem, which might stem in part from his past experiences, is due in part to his understanding of the nature of knowledge and to the nature of learning. KY has a positive outlook toward

acquiring new knowledge in the field, and is open not only to receiving the officially sanctioned teachings of authority, but also to developing his capacity. KY's pragmatic sense that knowledge must be connected in some way to an authority does not entirely dampen his confidence in his independent subjective evaluations. As he himself remarked:

I still think my answer is right [but] I'll remember my teacher's answer because that's the one that's going to be counted right on the test. But I'll keep my own answer in my mind and work on it, and use that one on something other than a test that came up.

Even though his confidence helps him to enjoy science, to think independently, and to learn constructively, he is also shaped by the school setting in his tendency to accord greater validity to knowledge that consumed more time in the classroom; his awareness of competition; his striving for good grades, etc. These factors could not help but affect his constructive approach to thinking, reasoning, and problem solving.

Case 2: Kay

According to her science teacher, to her parents, and to herself, Kay had trouble with science. Kay said she was interested in living things. However, due to her slightly defeatist attitude and problems with the subject matter in science, Kay did not care for the subject. Not only was she quiet in science class, but her science teacher said that Kay had difficulty communicating her questions unless it was in a one-on-one situation. Even then Kay consistently spoke of her lack of ability in science.

Kay usually sat in the back of the class. Before the class began she talked aloud with friends and laughed, but once the class began she never involved herself in whole-class discussions

unless the teacher directed her to answer. When she took a test during the period of my observation, she finished very quickly, and did other things, e.g., drawing a picture, reading books, or watering plants. Kay defined science as follows:

...a class that is required in school for you to graduate. Science is about plants and animals. You learn about how plants reproduce. Combining and mixing chemicals and molecules. For some people science comes easily and for others science is tough. When science gets boring and impossible then we do an activity or a puzzle on the overhead. If you have problems on a quiz there is extra credit to help get a decent grade on the quiz. Science is a class you are going to take for a long time. Without science you could not graduate or have much of a career. That is what science is to me.

Epistemological Commitments

Kay very much relied on her belief that a piece of knowledge is true, and she used various sources of "authority" to justify her reasoning while solving a problem. Kay accepted knowledge that was handed down from authority as an act of faith. Thus for Kay, science teachers, parents, and other "authorities" are the central purveyors of the validation of knowledge, and their role in the process of learning is necessary. Kay's willingness to accept knowledge from authority without questioning her lack of understanding manifested itself when she spoke about the interview topics. Kay accounted for her knowledge by stating that it had come from science teachers, adding, "*They [science teachers] got to be right, otherwise they can get money for nothing.*" She continued by saying, "*Because they [textbooks] have earned a lot of money out of that.*"

Kay's tendency to be a received learner led her to give credence to the ideas and opinions of

almost everyone except herself, thus one could argue that she had a very broad definition of authority. Kay very much believed in the "majority rule" when deciding whether or not a piece of information was valid. "*Not everybody is, can be wrong...well, if you have like a group of 20 people and they, they and all them say that's what day it is, and it's got to be.*" Further, the majority, in Kay's eyes, did not always have to be much of a majority at all. For Kay, she would automatically discount her own thinking "*if there is more than one person*", as she said, in a group who differed with her.

As this example shows, even though Kay has the capacity to struggle with a widely-accepted piece of knowledge, she defers to dependent thinking in general.

Metaphysical beliefs

Metaphysical beliefs, that is, beliefs in the ultimate existence of qualities or properties of objects or phenomena, emerged frequently in Kay's discourse, and especially in her answers regarding why leaves change color and fall from trees in the autumn. When we asked Kay why some leaves are yellow and other red, the response was, "*It [the tree] wants to,*" as if the tree had a will of its own. Moreover, some things are not explainable. The ultimate expression of Kay's conclusion is that "*It's just the way it is, I don't know. It's just the way the seasons change.*" Kay relied on what other people told her when she had to decide whether to accept a piece of information or not. For example, she committed to a rather simple idea of God because many people believe so: God is good, and God helps people. Because she has relied on this notion, and has not created her own view of God, she ultimately does not believe there is a God, arguing:

If there's a God, then how come there are always kids dying by guns? How come there is all these wars? How come there is like incurable diseases? How come there is

all of that if there is a God? 'Cause everybody looks up to him, he's gotta be. He can't be like some guy who goes around torturing people. That's not what a God is supposed to do. He's supposed to help you, not hurt you.

Affective domain and emotional aspects

In the beginning of the interviews, Kay looked very cheerful, and she seemed to be interested in my study. As the interviews progressed, Kay seemed uncomfortable, struggling to answer the questions about leaves changing color and falling off trees offered by the interviewer. Moving beyond the superficiality of topics made her frustrated and confused. Kay had a general dislike of elaborating about her answers. Her initial responses were most often one or two words, and usually began with “*Well, I am not good at it [science],*” or “*I don't know.*” As she herself commented:

It's [science] boring, it's stupid, I get frustrated, I don't like it...I just forgot about science to begin with. Because I've never been good in science. I've never understood science...I don't like science, 'cause I don't get it.

Kay's statements during the interviews more than bore out her teacher's observation that Kay was skeptical about her capacity to perform well in the subject. Indeed both self-deprecation and defeatism marked many of Kay's statements. “*Why study something you don't understand?*” she asked:

If something doesn't make sense to me, then I just forget about it...'cause if I don't get it now, I don't think I'll get it ever... I am not good at science...bad memory... I can't memorize...[I'm] probably not smart enough. I've had like this guy I know, he's been tutoring me in science, it still hasn't helped me any.

Kay further believed that she only confused people when she explained her idea or an answer: “*I'm confusing you, ain't I? I do that to a lot of people... They don't understand me. (Why?) I don't know, they just never do. (Who are they?) People, [science] teachers, friends...*” Because she doubted her ability to communicate, she also questioned her ability to learn science.

When Kay was asked to develop her own leaf model in whole-classroom discussions, she drew a typical leaf shape with veins, and commented, “*This is a leaf that we see everywhere...*” When she was asked how she came to develop her model of a leaf, Kay seemed disinterested in building her own model. Rather, she built a model of a leaf that everyone accepts as a leaf. Ultimately one can infer that Kay did not seem to have confidence in her capacity to build her own leaf model.

The nature of knowledge & learning

Kay viewed knowledge as consisting of facts to be memorized to satisfy the very authority (the science teacher) from whom much of that knowledge had come. For her, knowledge was something that existed in the realm of authority, whether that authority was a teacher, parents, or a book. This form of knowledge even superseded understanding. “*I don't know what photosynthesis is,*” she commented, “*but I can look it up.*” Knowledge for Kay was something that could be presented by an authority who in turn justified or validated it. Thus Kay commonly made statements such as the following: “The science teacher told me. They got to be right, otherwise they can get money for nothing.” As noted previously, however, there were many sources of authority in Kay's life: “*They [science teachers] taught it to me in science class...Y eah... the teacher doesn't have to teach you...I mean, parents teach you things, not just teachers.*” Kay saw knowledge coming from textbooks and other sources of authority as well. Because Kay regarded knowledge as the possession of experts and hence external to

herself, she found that some knowledge was useless to her or even to people in general. Thus Kay's concept of the nature of knowledge was connected to an important aspect of her affective domain—becoming disengaged. In science class, then, Kay frequently questioned the utility of knowledge and could not see the applicability of much that she was taught. It was not surprising, then, that Kay's attitude toward knowledge was that I don't need this, then why do I study? As she explained:

Why do you really need to know what a plant cell looks like, if you're going to be an accountant, or if you're going to be a lawyer, why do you need to know what a plant cell looks like and an onion cell? ... if you do go into nursing or that, or become a doctor. But like, plant cells, what's a plant cell gonna [teach you]? What do you need to know that for a nurse? No kid is a plant. So, they aren't going to have plant cells in them. Same with an onion cell. Why do you need an onion cell? Why would a kid have an onion cell in their finger?

Kay believed a piece of knowledge was acquired through memorizing something that exists in the realm of authority. As noted above, she regarded knowledge as something that could be "looked up." And she frequently asserted, "*I can't remember... I can't memorize... bad memory...*" Kay equated her difficulties in memorization with a lack of aptitude in science. Therefore, she believed that only the smarter students in the class were capable of learning, stating:

Jean is smarter, so he's probably got the right idea. Better grade point average. Well, he's probably like one of the top ten percent in the class. And I'm like probably like the 60 some percent of the class. Because I'm not smart enough to get it [science]. Like people, like, Jean and Wan

and all them, who gets A's on every paper, are good, I'm not.

For Kay, knowledge had to be official in that it was backed by some form of authority, and it could not be learned through happenstance. Note in the following example, Kay also distinguishes between forms of learning, weighing them in importance according to whether they are necessary in a formal academic sense:

Depending on what it is, like if, somebody just said, 'Oh, she got a A on her test,' you don't really learn that, I mean, it's not something that you're going to need to learn. But like, if somebody told you like, E equals MC2, that's something you learn.

It is important to note that Kay made statements during the interviews that indicated she slightly recognized that understanding and comprehension might be an important part of the nature of learning, and that learning could be more than mere memorization. Further, she also seemed aware that her attitude was connected to the process of understanding, stating, "*If I understand something, that probably makes [me] be more interested.*"

Problem-solving strategies

Kay's reliance on authority directly affected her problem-solving precisely because she regarded problems as entities that came from teachers or textbooks. This in turn encouraged her belief that solutions to problems were not those that emerged in the course of her own thinking but those that came from teachers or those that were stated in a textbook answer key. As Kay noted, "If she [a science teacher] assigned it [a problem] to us she has to know, otherwise how would she have gotten the answer to the problem." Thus since she was dependent on authority, Kay assumed that she could not get a right answer to a problem because of her poor memorization skill alone.

Discussion of Kay

Science is not Kay's favorite subject, and as previously noted, she regards herself as "not good at it." Much of Kay's affective aspects seem to spring from her understanding of the nature of knowledge and the nature of learning. Her dislike of science flows from her belief that she could not "get" a piece of knowledge (that came, of course, from an authority) because she has a "bad memory." Self-deprecation is the most obvious facet of Kay's affective domain, and this is closely related to her epistemological commitments, the nature of knowledge, the nature of learning, and the problem solving. Because Kay considers knowledge to be absolute truth if held by authority, then she does not question that her source of learning knowledge is embedded in her understanding of truth that came with her face-value acceptance of what the teacher said. Because of this, Kay has few occasions to question authority. One can assume that her attitude about authority comes from her past experiences.

Kay's attitude toward science and her definition of knowledge are supported by a sense of skepticism about learning in general. "*Why do you really need to know what a plant cell looks like,*" she asked, "*if you're going to be an accountant?*" This skepticism blends with her sense that to be "useful," and, perhaps, to be valid, knowledge should be part of daily existence. "*[A] phone number is used all the time...same as my name, but photosynthesis I don't use all the time, so I don't remember.*" Not surprisingly, knowledge for Kay is what an authority requires students to learn, which is what inspires this particular student to make a distinction between information that she absorbed without effort (such as a phone number) and information imposed by the school environment. "*E equals MC², that's something you learn,*" she remarked. Knowledge, then, has to be explained and memorized to be learned, and in Kay's view, only the smarter students in

the class are capable of learning. Especially, Kay believes Jean (or Wan whom she added in later discussion) had and knew more scientific knowledge and would have the right answer because they had, "Better grade point average... *Well, he's probably like one of the top ten percent in the class. And I'm like probably like the 60 some percent of the class.*"

In problem solving, Kay regards problems as coming from teachers or textbooks and her view of a problem links to her view of knowledge. She does not question that only an authority could have the right answers. Arriving at solutions to problems is equally as "external" for Kay, who is also affected by her lack of self-esteem in this regard: "I ask my friends what they got and I compare mine to theirs. If it doesn't [compare] then I know that's not right. 'Cause there's a good chance that three out of five people will be right compared to me."

General Discussion

The cases of KY and Kay bear out the conclusions of Strike and Posner(1992) in that they both show how various components of an individual's conceptual ecology are inter-related and fluid in terms of the boundaries that exist between them. KY's enthusiasm to pursue science was closely connected to his views regarding the nature of knowledge, the nature of learning, and his epistemological commitments, and influenced him into an independent pursuit of the questions that interested him. Kay's low self-esteem *vis-à-vis* her performance in science class played an equally important role in her life, and discouraged her from delving deeper into scientific phenomena on her own. Her dislike of science flowed from her belief that she could not "get" a piece of knowledge because she had a "bad memory." Self-deprecation was the most obvious facet of Kay's affective domain, and, as shown above, this was closely related to, or resulted, in her epistemological commitments, and her view of the nature of knowledge, the nature of learning, past

experiences, and problem solving.

In KY and Kay's cases, the components of conceptual ecology are mutually influential and are consistent with one another. Indeed, their epistemological commitments are closely related to their views of the nature of knowledge, the nature of learning, past experience, and to problem-solving strategies. KY's epistemological commitments are consistent with his confidence. That is, KY justified his reasoning based on his epistemological clarity because he had confidence in his ability. KY accepted authority only under specific conditions. When there were conflicts between his beliefs and the teacher's explanation, he resolved the situation by relying on his epistemological clarity.

KY's self-confidence allowed him to determine when he would use his own explanations or when he would use his teacher's. Because KY explored views that seemed plausible to him, he was able to use his confidence in such a way that the teacher's explanations would become his own if he agreed with them. Much of KY's confidence was closely connected to his understanding of the nature of learning that included himself as a center of learning. KY's view of the nature of knowledge, in which experts were responsible for producing knowledge which could then change or undergo revisions, helped to underpin his sense of confidence. KY's enjoyment of science was directly linked to his confidence, and to his ability to reason, and was due in part to his understanding of the nature of knowledge and to the nature of learning.

In the case of Kay, she does not justify her reasoning based on her epistemological clarity because of her self-deprecation. Since Kay's lack of confidence so influences her epistemological clarity, she relies on authority to justify a piece of knowledge. Much of Kay's affective aspects seem to spring from her understanding of the nature of knowledge and the nature of learning. Kay's dislike of science flows from her belief that she could not

understand a piece of knowledge because she has a bad memory. Because Kay considers knowledge held or conveyed by authority to be the absolute truth, she does not question her source of learning knowledge. Thus her understanding of truth comes with her face-value acceptance of what the teacher said.

It would be mistaken to give greater primacy to one aspect of an individual's conceptual ecology over another, and although both portraits of the two students emphasize, at times, some of the components of their conceptual ecologies, one must recognize the impact of the intermingling of components above all. In both cases it would be difficult to determine which component played a more significant role during their answering questions. Moreover, there may be other factors that an examination of conceptual ecologies alone cannot lay bare, such as culture. As both students mentioned during the third interview, (and the science teacher concurred), Kay came from an economically disadvantaged background while KY's family was more affluent. It is also possible that an individual can be a received learner in one context, and can be a constructed learner in another context. Therefore, I do not want to draw the over generalization that Kay is a received learner in all contexts or for that matter that KY is a constructed learner in all cases.

Nonetheless a comparison of two students can amplify and illustrate a series of conceptions that otherwise appear one-dimensional. As we see above, Kay's conceptual ecology and the way in which her conceptual ecology produces a "learner" and works in the process of answering questions is different from that of KY. Ultimately conceptual ecology is a very unique and personal aspect of an individual's conceptual knowledge development, as the portraits of KY and Kay reveal. What an individual's conceptual ecology looks like can influence how her conceptual ecology produces knowledge and works in the process of answering questions.

IV. Conclusions and Implications

Inferences concerning selected components of students' conceptual ecologies were made by analyzing students' statements that were made in the process of answering questions during interviews. The students' statements have shown how specific components of the students' conceptual ecologies have the potential to influence both the way in which a scientific natural phenomenon is understood, and the answers to questions about that phenomenon. Throughout their answering questions these students provided arguments about their ideas that were often well-reasoned and insightful. Their comments were an indication of the commitments they had to particular components of their conceptual ecologies.

When students were asked questions, there was evidence of the engagement of the various components of conceptual ecologies. Among these were epistemological commitments, metaphysical beliefs, the affective domain and emotional aspects, the nature of knowledge, the nature of learning, past experience, and problem-solving strategies. Evidence from this study suggests that these components function as constraints. For example, the answering of questions is affected by the students' views regarding what a teacher expects of them and what the classroom setting imposes upon them in general. Central to the context of the school setting is that the students relied on an authority (such as the teacher) to decide what was important to learn what was a right answer. One can infer from the interview statements that how students anticipated the kinds of problems they would get on an examination in school influenced their learning of science.

Some students tend to believe that science learning requires that they remember the definitions of scientific terms even if they do not understand what was happening within a given phenomenon. Although the students often have their own conceptions of scientific phenomena

that they find plausible, they rely on an authority to decide what was an acceptable answer. The evidence suggests that in the process of validating knowledge that came from an authority, students construct a school-centered view of knowledge rather than one of their very own. No greater example of this exists, perhaps, than in the students' tendency to equate the importance of a piece of knowledge with the amount of time the teacher had spent in conveying that knowledge. Further, the students felt little responsibility to learn something that was not covered in class.

The students in the study measured their knowledge of science on the basis of their test grades, not on the basis of their own epistemological clarity. Moreover, they equated teachers in positions of authority with power, which meant that even when they did not understand a piece of knowledge, they accepted what the teacher had said without question. Students, then, were more concerned with getting good grades or passing the class than they were with learning science.

This research has suggested that two things facilitate and are facilitated by growth in science competence. The first of these is related to one's affective domain which influences whether an individual has confidence in her ability to understand scientific knowledge, and to approach learning science as a matter of understanding instead of learning by rote. As I have shown above, Kay's conviction that she has no ability in science is coupled with her lack of interest in the subject. A second factor that has bearing on science competence is whether an individual values learning science and solving problems for her own sake rather than for someone else's. As the cases of KY and Kay suggest, an individual's affective domain and emotional aspects function as motivational variables in the learning of science and can influence how that person looks at the nature and the value of a particular subject matter.

Another finding of this research is that the

nature of an individual's conceptual ecology affects how she learns scientific knowledge and answers questions about that knowledge. For example, a received learner's conceptual ecology uses various sources of authority to justify reasoning while answering a question. Thus a received learner relies on memorizing something that exists in the realm of authority in order to learn. A lack of confidence prevented Kay from solving problems as well as from learning science in accordance with her own potential epistemological clarity. Clearly a received learner who does not see why she should study a unit and what interests she may have in that unit is unlikely to engage solving a question for its own sake. More likely, she will memorize some facts to answer a question.

A constructed learner views all knowledge as contextual, regards herself as a center of learning, and values both subjective and objective strategies for learning. KY, for example, is motivated by his curiosity about science and solved problems that required metacognitive reflection. This not only facilitated his learning of science, but ultimately assured that he would enjoy science.

As the findings suggest, learning styles differ according to distinctions within individuals' conceptual ecologies. Thus the way in which a person learns science varies according to the construction of her conceptual ecology. This suggests that different forms of pedagogy may be effective with different types of learners. This also suggests that science educators may have a role in assisting students to develop into constructed, rather than received, learners.

In summary, this study focused on describing two individuals based on salient features of their conceptual ecologies, beyond understanding the nature of the learner from the perspective of constructivism. Moreover, this study shows a great richness regarding the nature of learners that goes beyond the categories of Belenky et al. (1986). One should recall that the assumptions of the categories devised by Belenky et al. were

based on how students' views of constructing knowledge vary depending on their sense of self-esteem. But Belenky et al. do not make any connection between the nature of knowledge, the nature of learning and the affective domain (self-esteem and/or self-image), nor these components with other components of conceptual ecology. What we have tried to do in this research is to understand who the learner is by exploring the components of that person's conceptual ecology, and by positing and examining the inter-relationships between these components. Since the notion of conceptual ecology provides a context for understanding an individual's learning in terms of the environment in which all information is interpreted, the nature of the components of an individual's conceptual ecology do indeed come together, and in the process, build complex relationships.

Pedagogical content knowledge develops when a teacher begins to shift her focus from content knowledge to the nature of her students. The kind of pedagogical content knowledge that develops depends on how a teacher views the nature of the learner. A teacher must understand all of these kinds of learners and develop pedagogical content knowledge that not only helps her students to build an understanding of the process and content of the discipline, but facilitates the transition of the students toward constructed learners. This implies that the teacher must concentrate a great deal of her attention on the comments made by students in order to evaluate individuals' conceptual ecologies. The received learner and constructed learner, for example, represent two extremes in the learning spectrum. That these two types of learners require different pedagogical approaches suggests that all other types of learners could benefit from appropriate pedagogy on the basis of develop conceptual ecology.

In the case of a received learner, the teacher needs to focus on the affective domain in order

to motivate the student to believe that an examination of her conceptual ecology is a reasonable means of thinking about her learning. A received learner is unlikely to solve problems for her own sake in a school setting unless she is self-motivated by having confidence in her ability, by seeing herself as a center of her learning, and by understanding knowledge as contextual. Students would show more success on a scientific task, when they asked themselves whether they would complete it than when they told themselves they would. Students not only did better as a result of the question, but that asking themselves a question did indeed increase their intrinsic motivation. The popular idea is that self-affirmations enhance people's ability to meet their goals. If a received learner is to come to view herself as a legitimate source of knowledge, she must find reliable ways to validate her new knowledge outside of the authority of the teacher and other experts. Once this occurs, a received learner is moving towards a constructed learner. This may require the teacher to spend time exploring what each student thinks about learning and the role of a learner. A teacher, then, must help students come to value themselves as legitimate builders of knowledge.

In the case of a constructed learner, focus on a metacognitive reflection is pedagogically effective. Providing a constructed learner with the opportunity to engage in metacognitive reflection will facilitate that individual's learning of science. A constructed learner needs to think not only about the ideas themselves but also about the thinking processes necessary for evaluating ideas. It is critical for the teacher to probe beneath students' statements to find out why students believe what they do. This is not to devalue propositional statements made by the students but to force the students to become metacognitively aware of the statements they put forth. Clearly learners who have a language with which to comment on their ideas can provide statements indicative of metacognitive

reflection. This metacognition can take the form of comments on the status of a conception, and comments on status can then be analyzed by the teacher for references to the conceptual ecologies within which those conceptions exist. This information provides the teacher with an indication of the student's commitment to the conception and supplies her with valuable information about the learner's conceptual ecology that may need to be addressed through future instruction. For example, if a student expressed a metaphysical belief in an egocentric view of leaves changing color and falling off trees, the teacher would need to confront that belief through carefully selected instructional activities and discussions. The activities and discussions would need to present the student with opportunities to judge the status of the conception (Driver *et al.*, 1994).

One significant inference to be drawn from the cases of KY and Kay neither received nor constructed learners benefit from process in which a teacher transmits content knowledge as an authority. A teacher, then, must embrace a constructivist view of learning since it has many implications for the learning that will take place. Such a view includes, but is not limited to, the choice of science concepts, the design of instructional activities that address difficult conceptual issues and/or the selection of types of problems. A teacher must find ways to challenge her students so that they may come to see the problematic nature of their conceptual ecologies. Additionally the teacher must also find non-threatening ways to direct her students to the problematic features of their conceptual ecologies. The teacher must encourage a belief on the part of her students that they are capable of constructing new and valuable knowledge. At the same time, the teacher must be careful not to use her authority as a way of validating any conception during classroom discussions, but must defer to whatever scientific criteria of knowledge validation she had introduced into the class.

For an implication for teacher education programs should help teachers become aware of the significance of the extensive nature and importance of a student's conceptual ecology. One way of doing so, for example, would be to help teachers become aware of their own conceptual ecologies. Teachers must begin to explore their own conceptual ecologies, asking, for example: What kinds of learner or teacher am I?; What is the nature of science?; What is the nature of knowledge?; What is the nature of teachers and teaching?; What is learning? From this, teachers can better understand the nature of the learner and can facilitate students' learning more effectively and talk about the techniques used in order to do so as ways that teachers could use with their own students.

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