ability students generally utilized their prior knowledge in lower-level thinking. For example:

> AA1:[Moisture comes] from the soil when you water the plant (AA1,B,6). Moisture leaves the pot.... it just evaporates, it's not there any more (AA1,B,8).

This student expressed prior knowledge concerning the source of water for the plants (AA1,B,6). It was evident that this knowledge lacked integration and was probably knowledge that comes from first-hand experiences. Subsequently, this knowledge was utilized to predict that the moisture would eventually evaporate from the pot (AA1,B, 8). The student demonstrated the ability to comprehend the prior knowledge that was available and consequently made an extension of this understanding by identifying that water will eventually evaporate. This is evidence of low-level thinking.

Another average-ability student utilized prior knowledge that lacked integration in low-level cognitive behaviors. For example:

> AA5:[the sun] can dry out the leaves fast because the water evaporated from the leaves (AA5,B,14). Why you have to water [a plant] is because water

evaporates fast (AA5,B,16).

The student understood that water evaporates from the leaves (AA5,B,14), but did not substantiate the claim by relating water-loss with knowledge about the process of transpiration. This is prior knowledge that lacks integration. In turn, the student asserted that because water evaporates from the leaves, plants have to be watered (AA5,B,16). She expressed her prior knowledge in lower-level thinking by restating her prior knowledge without making further applications of her knowledge.

The protocols thus revealed that the average-ability students in this study utilized prior knowledge that lacked integration to exhibit low-level thinking. This might be a characteristic of other average-ability students as well. Furthermore, there was also evidence that these students typically demonstrated low-level thinking even when they had relevant, well-integrated prior knowledge. For example:

AA1:[Plant] grows when sunlight is coming all around it (AA1,A,4). If there is not much [sunlight], [the plant] will die (AA1,A,5).

AA4:[water] will go up the stem and go up the leaves (AA4,B,12). That's how leaves get fed (AA4,B,14).

AA2:[plants] are able to photosynthesize (AA2,A,8).... when they photosynthesize, their leaves turn green (AA2,A,9).

In these examples, the students clearly possesed well-integrated knowledge that defines the conditions in which plants could grow (AA1,A,4), decribes the properties of plants (AA4,B,12), or defines the properties of plants (AA2,A,8). However, these well-integrated prior-knowledge statements were expressed in lower-level thinking that corresponded to first-hand experiences (AA1,A,5; AA2,A,9). In addition, there was also evidence of poor use of scientific terminology (AA2,A,14).

In summary, analyses of students protocols revealed that high-ability students were more able to utilize their prior knowledge in demonstrating higher-level thinking. The average-ability students, regardless of the nature of their prior knowledge, were unable to effectively utilize their prior knowledge to demonstrate higher-level thinking processes.

CHAPTER 6

Summary and Implications

The objective of this study was to investigate how prior knowledge was utilized by high-ability and average-ability students to make predictions. Specifically, a comparison was made between the two groups of students in the context of science problem-solving. In addition, three science lessons that focused on teaching students how to access and utilize prior knowledge were implemented. Students were given two problem-solving scenarios, one before and one after these lessons. The utilization of prior knowledge during the two problem-solving scenarios was compared. The goal of this comparison was to investigate whether effective problem-solving skills can be acquired.

Students of both ability groups met with the experimenter individually. They were each given a problem-solving scenario to consider; their "think aloud" protocols were audiotaped. Subsequently, all the students attended a mixed-ability class; it was intended that a teacher would deliver three science lessons that emphasized the accessing and utilization of prior knowledge in problem-solving activites. The experimenter observed these lessons and audiotaped the teacher-student discourse. Following, the high-ability and average-ability students were then given another problem-solving to consider and their responses were audiotaped. In addition, the students were also interviewed by the experimenter after each of the problem-solving scenarios in order to gain information about students' sources of prior knowledge and understanding of knowledge utilization. The methodology used in this study incorporated qualitative and quantitative analyses of students' verbal protocols gathered during the problem-solving scenarios, interviews with students and teacher-student discourse during the science lessons.

The utilization of prior knowledge in the prediction-making process was qualified using two measures. The level of integration of prior knowledge was first established to provide information about the way in which the two groups of students organized their prior knowledge. The level of thinking exhibited during the process of making predictions was subsequently identified. Examining the relationship between these two measures aided the understanding of how prior knowledge, organized at different levels of integration, was differentially utilized by the two groups of students during the prediction-making process.

Results and Conclusions

The results of this study revealed that the science lessons alerted students to the importance of accessing prior knowledge during problem-solving situations. The lessons, however, were not successful in demonstrating how prior knowledge could be utilized. The shortcomings of the lessons may have been a result of not providing the teacher with sufficient training prior to her delivery of the science lessons.

Results of the two problem-solving scenarios also suggested that high-ability students possessed well-integrated prior knowledge, while the average-ability students typically possessed prior knowledge that was not as well-integrated as their high-ability counterparts. There was some indication that well-integrated prior knowledge among high-ability students was associated with their broad repertoire for acquiring information and knowledge.

The high-ability students in this study displayed more instances of higher-level thinking, in contrast with the average-ability students who frequently displayed lower-level thinking behaviors. In addition, the high-ability students, when compared with the average-ability students, showed more sophisticated use of their prior knowledge in executing higher-level thinking processes.

Implications of the Study

Analysis of the average-ability students' responses indicated that they were less able, when compared with high-ability students, to organize their knowledge in a well-integrated manner. Beyer (1984) suggested that average-ability students lacked the necessary skills to establish relationships between ideas. Further research is needed to identify the cognitive and metacognitive processes by which students construct linkages between related ideas and knowledge. Comparative research with this focus can attempt to identify the processes that are characteristic of high-ability performance and learning, so that these processes can be made explicit in enrichment curriculum.

Students' protocols also suggested that the high-ability students were more successful in utilizing their prior knowledge to display higher-level thinking. It was also apparent, in the protocols, that high-level thinking was often associated with the utilization of well-integrated knowledge. On the contrary, average-ability students, who were less capable of higher-level thinking, were unable to do so even when they possessed well-integrated knowledge. This leads to the speculation that average-ability students cannot readily retrieve and utilize their well-integrated knowledge, suggesting that they may not be aware of the integration of their knowledge. Further research is necessary to explore students' understanding of the their knowledge structure. It is also important to examine how such an understanding can facilitate the utilization of one's prior knowledge.

The results of this study suggest that it may be beneficial to provide students with enrichment that emphasizes extensive integration and organization of one's knowledge during learning situations. In organizing knowledge hierarchically by relating specific knowledge with general knowledge, the utilization of prior knowledge in problem-solving situations can be facilitated (Reif, 1980; Reif & Heller, 1982). High-ability students will be expected to develop more effective utilization of their prior knowledge with an enrichment focus as such. In particular, the need to establish integration and organization of knowledge is augmented among average-ability students, since they typically lacked such skills.

It is also important to examine the effects of explicitly teaching students skills and processes that are crucial for successful problem-solving. This study failed to demonstrate that such instruction is beneficial to high-ability and average-ability students, but the belief that using questioning techniques appropriately can stimulate higher-level thinking is prevalent (Bloom, 1976; Nasca, 1983; Redfield & Rousseau, 1981; and Taba, 1971). Further studies to look at the effects of teaching problem-solving skills should include adequate training for the teacher, so that accurate delivery of the teaching objectives can be assured. In addition, the treatment should be conducted over an extended period of time, so that students' transfer of learning can be facilitated.

In summary, this study provided some indication that high-ability students behave differently from average-ability students when they utilize prior knowledge to make predictions during problem-solving situations. The way in which prior knowledge is used is associated with the level of integration of the prior knowledge and the students' ability level.

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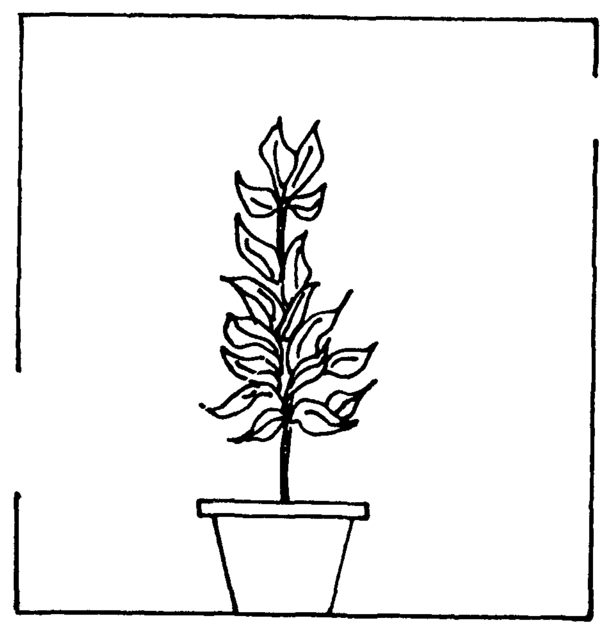
Appendices A and B

<u>First and Second Problem-Solving Scenarios</u>

Appendix A

First Problem-Solving Scenario

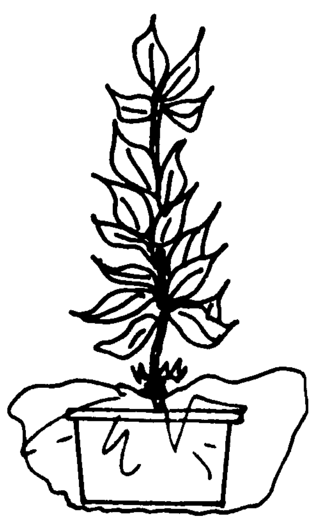
This is a plant that was placed inside a cardboard box. All the sides of the box are opague. There are two openings, one on the left side and one on the right side. Sunlight can only enter these openings. How do you think the plant would grow? What do you think the plant will look like after being kept in the box for a long time?



Appendix B

Second Problem-Solving Scenario

This is a plant that has been watered. A plastic bag covered the entire pot and is tied tightly at the base of the stem. All the leaves and branches are not covered by the plastic bag. The entire plant, including the pot, the soil and the plastic bag weighs about five pounds now. If you leave this plant in the open for a few weeks, how much du you think it would weigh? Would it be more? or less? or just the same?



Appendix C

Samples of Verbal Protocols

<u>Sample of Verbal Protocol of a High-Ability Student</u>

HA3: The plant is in a box and the light comes through here. O.K. the plant usually... usually it will try and grow toward the light coming in.

Exp(Experimenter): O.K. You said that the plants usually grow toward where the light is coming in. How do you know that?

HA3: Last year in our science class we had a study on plants, about soil, minerals and chlorophyll and everything that went on to help the plants grow.

Exp: I see. And what does mineral have to do with the light source?

HA3: Well the minerals, they come from the light source. Like, the light comes in and then changed by the plant into some sort of minerals that they like.

Exp: And wht about chlorophyll?

HA3: The chlorophyll is also made by the light and it makes the leaves green.

Exp: O.K.

HA3: It need the light to grow. Sunlight helps with the, uh, I forget the word. But it helps with the leaves and that. The leaves have chlorophyll on it, so they're green. Sunlight helps the chlorophyll and turns the leaves green.

Exp: You talk about the chlorophyll making the leaves green. How do you know that? Where did you learn that from?

HA3: Yes, we had some tests on it; the plant structure and that, and what helps the plant and what makes the leaves turn green.

Exp: Where did you learn that?

HA3: Well in grade three, I think it was, we also did something like this. We put a plant, hid it in a box for about two weeks with a light source at the top and the plant turned toward the light source.

Exp: Oh, O.K. The light source was on the top so the plant just grew toward the...

HA3: Yes, it was in the corner here. Like the box was like this (tracing the boundaries of the box) and it was in the top right corner. So we put the plant here and then it started to grow toward the light source.

Exp: Oh, O.K.

HA3: From light source, like, it gets most of its energy.

Exp: You mentioned something about energy. What were you referring to?

HA3: Well the sun helps it grow because it makes the salt and minerals. And the minerals are what basically what the plant needs to live. And that's like its energy.

Exp: O.K. Where did you learn that?

HA3: Um, I don't know exactly when. Like it's mostly experience in different grades and that that I've learned it.

Exp: Can you tell me a bit more? Give me some examples of the experience you've had?

HA3: Well, like I said, the box that we did in grade three. The light. We left it. It was just right under the light source. Like the top of it had grown straight. Until it got to the top and then it started curling over to the light source at the top of the stem. And that's what happened there. And when we lifted up the box, the bottom leaves were a bit brown because they hadn't been getting a lot of sunlight but the top ones were really green. Because they were getting a lot of sunlight.

Exp: O.K.

Exp: Can you think of anything else at all? Would you care to explain? At the beginning you said that plant will grow towards the light. There were two light sources here.

HA3: It'll grow usually towards the larger one.

Exp: O.K. Why would the plant grow towards the larger opening?

HA3: Because it will give it more sunlight. It will give it more chance for getting the minerals it needs to live because of the bigger the light source coming in. So it's more energy given.

Exp: Are you saying that if there were two light sources, one's larger and one's smaller, these light sources will compete with each other. The larger one will attract the plant more.

HA3: Yes.

Exp: Can you describe to me how the plant will grow?

HA3: Yes, well it starts off... Like when it's small, like you said, it will go towards the bigger one because it will really need a lot of light. But then when it gets older it will tend sort of like turn away from it and go towards the smaller one.

Exp: O.K. When you said the plant is older, what do you mean?

HA3: When it's been growing longer. Like the more it's grown. Like after you've just planted it and it just started growing. Like it's going to tend to turn towards the big light source because it can't really get to this one. Because it's really far away. When it first starts off. So it's really a weak light so you can't really tell that it's there, sort of. It's like looking up uh, in the dark or something, on the beacon of a building. And if there's a light, say, all the floors were gone, there was a light at the top, and then there was a light at the side by the door, you're going to see the light from the side of the door more than you're going to see the light at the top of that high storied building.

Exp: Oh, O.K. And you think that the plant is naturally attracted to the larger one.

HA3: Yes, when it first lights up.

Exp: O.K.

Exp: It'll bend towards the light.

HA3: Well, it will get to the light, actually, when it starts growing out.

Exp: It would get out of the box?

HA3: Yeh.

Exp: What makes you think that the plant if going to get out of the box?

HA3: Well, it's going to try to at least. Because once it gets out of the box, it's going to get as much light as it needs all the time. And it won't have to count on the little holes that are in the box.

Exp: Have you learned that from somewhere else? Is there any experience that you've had with plants that tells you this?

HA3: Yes. Once, in grade three, like we did this a couple of times. And it was a really large hole. Like about this big. About a couple of inches, and we planted it and only within a week it had grown out of the box.

Exp: Um, um.

Exp: What about the top of the plant? What would happen to this part of the plant if it is going to grow out of the box?

HA3: Well, if it was in this stage it would grow towards the top of this box, cause it's bigger, and you can't really, like it would droop all the way down. Like if it ws smaller, then it would grow out, like that. But if it's this size, it could bend all the way down, so it will probably be more attracted to the larger light source.

Exp: Can you tell me a little bit more? If it's growing, what do you think the shape is going to be like?

HA3: Um, what do you mean?

Exp: Like you said, part of it is going to grow to the left and some of it is going to grow to the right. Can you tell me what shape you think the plant will be?

HA3: I think it will be in a regular shape. Some leaves will be out, some leaves will be in...

Exp: O.K. Earlier you said some leaves are going to be out. You're referring to this left side of the plant where the larger light sources. What do you mean that some leaves are going to be out?

HA3: Well, if there's a stem straight and the leaves on this side are going to tend to be in more and the leaves on this side are going to want to stretch towards the light source. Even the ones on this side might want to wrap around the stem and go for its light sources.

Exp: O.K. Do you think the leaves will grow bigger?

HA3: Yes, will tend to because they're getting a lot more light than the ones that are on this side.

Exp: How do you know that with sunlight the leaves would be bigger?

HA3: Well, the sunlight helps the entire plant grow. And it's just a matter of time before you're going to see a difference.

Exp: O.K. I remember earlier, you said, in your grade three experience, when the plant and the leaves at the bottom of the box, the leaves are brown.

HA3: Yes.

Exp: Can you in some way relate the two comments that you make? The fact that without sunlight the leaves are going to be brown, and with sunlight the leaves are going to be bigger.

HA3: Well, the sunlight helps make the chlorophyll that keeps the leaves green and the chlorophyll also helps the leaves grow.

Exp: O.K.

HA3: And so, also some of the minerals that are in the plant.

Exp: Did you learn that from somewhere?

HA3: Yes, from science last year.

Exp: O.K.

HA3: And so the leaves are going to tend to get bigger because they're getting more sunlight which means minerals and more chlorophyll to keep them going. Whereas the holes at the top of the box, the leaves would still be pretty small but the ones as you went up, the leaves would be bigger and greener than the ones at the bottom.

Exp: If the light source is in it.

HA3: Yes.

Exp: O.K.

HA3: The stem, maybe, bend a little toward the light sources, both of them. So this part might be like this (indicating that the stem will curve toward the right slit) and this part over there (stem curving toward the left slit).

Exp: I see. Well just to give me a picture, do you think you could draw a picture of what it would be like over a period of time?

HA3: O.K. With the light source here (pointing to the right). Well, part of it will go over to here. And then, there's another light source up there and it's considerably bigger. It will continuously grow toward it, but not bending so much. The leaves will still stay here.

Exp: You said that there's a light source that's coming in. The leaves will still stay here.

HA3: Yes. Right! What I meant there that the leaves, the bottom leaves are going to stay like level with the hole in here and not want to reach upwards towards this.

Exp: Yeah.

HA3: Up until about the half-way point. Then the leaves will start turning towards the smaller light source.

Exp: Oh, O.K.

HA3: It might then start up towards the other light source (the top one). It has to grow. It has to keep growing so it's going to go this way.

Exp: Good! O.K. Can you think of anything else to tell me? About this picture?

HA3: No, no more.

Sample of Verbal Protocol of an Average-Ability Student

AA4: The leaves are in the middle here.

Exp: Yes.

AA4: That aren't getting any light. They will die or fall off.

Exp: Yes...

Exp: O.K. So you, here you just said that the leaves don't get light. That it's going to die or fall off. How did you know that?

AA4: From experience. From the plants in my house.

Exp: O.K. Can you tell me a bit more? What happened to the plants in your house?

AA4: Like some are in a dark spot, they don't get that much light so they die.

Exp: I see. O.K. Is there anywhere else that you could have gotten that information?

AA4: Information from books.

Exp: Could you tell me from what books?

AA4: From science books. No not really.

Exp: Is it books that you saw and read in school.

AA4: Yes.

Exp: Are they books that you read in class?

AA4: No. I just read them in the library, these science books.

Exp: Oh, a science book from the school library. O.K. Did you learn about the plants in science class?

AA4: Yes.

Exp: O.K. We'll go on and see what else you say.

AA4: And if the plant doesn't get any water, it will just die.

Exp: O.K. You mentioned something about water, saying that it would die. How does water relate to plant's growth?

AA4: Well, it gives it minerals and just feeds them.

Exp: The water would feed the plants minerals and is the food for plants.

AA4: Yes.

Exp: About water giving minerals to plants. Where did you learn that? Do you remember?

AA4: Last year. Mr. Law's science class.

Exp: Ah, O.K. He talked about water supplying the minerals to plants.

Exp: You can assume that it's going to be watered regularly.

AA4: Yes.

Exp: Yes. Can you think of something else?

AA4: Well. The leaves that are getting light will stay green...

Exp: O.K. You said that leaves that get light are going to stay green. Can you elaborate on that? Why would leaves stay green when they get light?

AA4: Because the sunshine gives it the chlorophyll. Sunlight will give chlorophyll.

Exp: O.K.

AA4: The light keeps it going or something.

Exp: I see. So it will stay green. Where did you learn that?

AA4: Mr. Law's.

Exp: In science class last year. Grade seven? O.K.

AA4: And once they aren't getting any light, will change colour, turn brown or just be plain white.

Exp: So when I asked you about leaves staying green, you said something about chlorophyll. And then later on when you said, "The leaves that don't get light is going to turn brown". Does chlorophyll have something to do with it too? Can you tell me how?

AA4: Without chlorophyll it kind of dies or just pulls away. It just dries up.

Exp: Yes, O.K. And where did you learn that?

AA4: Mr. Law's, too. Mostly in Mr. Law's science class.

Exp: I see. O.K.

Appendix D

Summary of Verbal Protocols

Included in this appendix are the summary of protocols of each student for the two problem-solving scenarios. The four columns, respectively, represent predictive statements, explanation statements, coding of statements using Bloom's taxonomy, and coding of statements using Langer's categories.

Classification of each statement using Bloom's taxonomy is represented by a numerical code. The correspondence is as follows: "1" represents knowledge level, "2" represents comprehension level, "3" represents application level, "4" represents analysis level, "5" represents synthesis level, and "6" represents evaluation level.

Classification of each statement using Langer's scheme is presented as follows: "L" refers to statements that lacked integration, "S" refers to statements that showed some degree of integration, and "M" refers to well-integrated statements.

HA1- First problem-solving scenario

Predictive statements	Explanation statements	B	L
Some of [the plant] would die or wilt (2,3)	because it doesn t have enough light (4)	4	M
	most plants need light to survive (5)	1	M
	plants need light to perform photosvnthesis (6)	1	M
[the plant] would reach towards top light source and maybe the bottom (7) and bend in the middle (8)	[the plant] lean towards light coming in (9)	3	S
	plants grow in the direction towards the sun (10)	5	S
	sun makes the plant get photosynthesis (12)	1	S
	photosynthesis is something that is [the plant s] purpose (13)	1	L
top of the plant bend towards light (14) [near the bottom light source] will grow another branch (15)	[the plant] will reach toward light source, which means growing a branch towards the light source (16) or it might just bend over (17)	5	S
	the bottom part is exposed to light so it [would not grow towards the light] (20)	2	L
	the tip is....not directly at the top light source	2	L
it may not be a branch, the stem may just bend [in the middle] (27)	[plants] need light to survive (28)	1	S
	[plants] fight for survival to get more light (29)	2	M

HA1- Second problem-solving scenario

Prediction statements	Explanation statements	B	L
[the plant] would get condensation in the bag (1)	with the plastic bag, water evaporates and rises...build up there and come back down again (2)	1	S
	[water rises when it is] hot and stick (4)	2	S
	water flows much too fast [in the plastic container (5)	2	L
	[plastic container] prevents [the water] from going up and spreading (6)	1	L
	[water build up] would fall back down again (7)	2	S
[the weight] might be a bit less (11)	All the water would be dried up and evaporated (12)	6	M
	Not all of [the the water in the plastic bag] would drop back cown again [after evaporated] (13)	3	S
	Some of [the water] that is evaporated would just dry up (14)	2	L
	water [that is evaporated] goes into the air (17)	1	L
	[The purpose of people watering plants] is to make them grow (19)	1	S
	Water travels up the stem stem (20)	1	L
	roots in the soil soaks up water (21)	1	L
	then up the stem and then it spreads out to all the leaves (22)	1	L
	the leaves have stems...and inside it will draw the fluid (24)	1	L
[the plant would weigh] less (26) [it would weigh less] but very slightly (27)	water will evaporate from the pores (25)	5	M

HA2-First problem-solving scenario

Predictive statements	Explanation statements	B	L
I think [the plant] would grow in the places where the light is coming in (2)	plants need light to grow (3)	3	M
	plants need light to reach the chlorophyl process (4)	4	M
	plants have photosynthesis coming through (5)	2	M
I think [the plant] is going to grow laster (8)	fluorescent light works better than normal light (9)	3	S
[The plant] is going to grow the same way, but is will frow faster (10)	because there is no light	5	M
[The plant] is going to get branches (11)	most of [the branches] are migrants (12)	1	S
	They will try and put more leaves there to take in the light (13)	2	S
If [the plant] need light and doesn't get enough...it would die (18)	[the plant] will only get light from the larger opening and the smaller opening (19)	2	L
I think [the plant] would try to get out. I think it might try to grow outward (20). It would sort of branch out (23)	[the plant] would get a branch out (21) then it would be able to get more light (22)	2	L
[the plant] may not grow out nut it will grow more leaves (24)	[the plant] got enough light from the opening so it does not have to go outside of the box for it (25)	6	M
If [a plant] didn t find light, it may die (27)	[the plant] wasn t getting enough food (28)	3	S
	[there are] minerals in the soils and in the water (29)	1	M
	[the plant] takes in minerals through the wet soil (30)	2	S
	It needs minerals to grow (31)	1	S
	[the plant] needs photo-synthesis (32)	1	M
	without photosynthesis, the plant won't make chlorophyl (33)	4	S
[the plant] would die (34)	there's no food (35)	5	M

HA2- Second problem-solving scenario

Predictive Statements	Explanation statements	B	L
[The plant] might die (1)	it might use up all the water (2)	2	L
	A plant uses water to grow (3)	1	S
	[a plant] absorbs [water] at the roots (6)	1	S
	[through the] veins in the stem, the water goes right to the leaves (8)	3	S
	[The water] stays in the leaves. It doesn t go any where (12)	2	S
	[the water] would evaporate if it got too hot (13)	2	M
[the plant] won t be able to grow any more (14)	because the plant needs water to grow (15)	4	S
	but it there is too much water [in the leaves], it would have to get rid of it or it will drown (19)	4	M
water may evaporate from the soil and there will be condensation in the bag (21) And water will drip back to the soil like a water cycle (22)	[water cycle] keeps going until [the plant] used up the [water] (23)	5	M
	The outside [of the bag] will be cold; there is air circulating; the inside is hot from the sun (30)	5	M
	Need hot and cold for the water to condense (28)	3	S
[there will be] less water in the pot (24)	[the plant] will be taking some (26)	5	M
The condensation will keep the plant alive for some more time (31)			
[The plant] is going to weigh more (32)			
[The plant] won t grow much in one week (33)			
[The weight of the plant] would probably be the same (34)			
I would say that [the plant] would weigh less (35)	[the plant] will take the water and sort of evaporates from the leaves (36)	5	M

HA3- First problem-solving scenrio

Predictive statements	Explanation statements	B	L
usually [a plant] will try to grow toward the light coming in (2)	[minerals] come from the light source (3)	1	S
	the light comes in and then changed by the plant into some sort of minerals that they like (4)	5	M
	chlorophyl is also kade by the light and it makes the leaves green (6)	1	S
Plants need the light to grow (7). From the light source it gets most of its energy (11)	The sun makes the salt and minerals (12)	1	S
	Minerals are basically what the plants need to live (13)	1	M
Sunlight helps the chlorophyl and turns the leaves green (9)	The leaves have chlorophyl on it, so they are green (10)	1	S
[Plants] grow towards the larger light source (16)	[the larger light source] will give [the plant] more chances for getting minerals it need (18)	4	S
	When [a plant] is small it will grow towards the bigger [light source] because it will really need a lot of light. When it gets older, it will grow towards the smaller one (19)	4	S
It will get to the light, when [the plant] starts growing out of the box (22)	Because once it gets out of the box, it is going to get as much light as it needs all the time (23)	2	L
The top of the plant cannot bend all the way down, so it will probably be attracted to the light source besides it (27). The stem may bend a little towards the light source, both of them (36)	The leaves on [the left side] are going to want to stretch towards the light source [on the left] (29)	2	M
	Up until the half way point, then the leaves will start turning towards the light source on the right (37)	5	M
	[The plant] has to grow. It has to keep growing this way (38)	6	M
The leaves [near the opening] will tend to grow bigger (30)	[The leaves near the opening] are getting a lot more light (31)	2	L
	Sunlight helps make the chlorophyl, which hepls the leaves grow (32)	1	L

HA3- Second problem-solving scenario

Predictive statements	Explanation statements	B	L
The plant is going to weigh considerably less (1)	The water in the pot is going to the leaves (2)	5	M
	The plant is going to use the water from the soil (3)	5	M
	The roots are going to use [the water] up for the plant normal growth (4)	3	S
	The plant needs water (5)	1	S
The water is going to be evaporated inside the bag (5) and the plant is going to use up the water so it will grow (6)	When it s hot, [the water] will evaporate inside the bag (7)	4	M
	When it eventually cools down it will go back into the pot. In that way the plant will use it and then whatevver is not used will evaporate onto the bag and so on. The cycle is repeated (8)	5	M
	[A plant] needs water to keep the stem and the leaves moist (9)	1	S
	The roots [absorb water] at the bottom, then it goes up to the stem. It breaks away into different leaves (10)	4	S
The plant would weigh less because of the evaporated water (13)	water evvaporates from the surface of the leaves (14)	5	M
	If there is no bag around it, then most of the wateer, even before it gets to the plant, is going to evaporate (15)	6	M

HA4- First problem-solving scenario

Predictive statements	Explanation statements	B	L
Parts of [the plant] is showing shades of light (2)	You could say it is reaction (3)	3	L
	We had to draw darker and lighter spots. First a lighter shade, then a darker shade (5)	3	L
[The plant] will eventually start growing towards where it would be getting the most light (7)	[the leaves with lighter shade] will grow efficiently. [The leaves with darker shade will] probably die (10)	4	S
	It is natural for a plant [to die] if it doesn t have the qualities like water, sun light (11)	5	M
	Right now some of the leaves have [water and sunlight], so it won't die (14)	4	S
I think [the plant] will try to get out of the hole on the top (23)	plants need water, light and temperature; if it doesn t have one of those it would naturally try to get after it (25)	2	S
[The plant] will bend towards the largest [light source] first (30)	[The plant] has to survive and go afterr the light (31)	5	S
	The more light the plant has, the better and longerr life it has (33)	6	M
	[A plant] will eventually die in the dark (34)	4	S
	[The smaller light source] is not doing its best. It is not feeding [the plant] enough light. [The larger one] is really giving it more light. Keep it alive longer (35)	4	M
[The plant] may grow towards the [small] hole, and then it will be lopsided (36)	because [a plant] need sun light to grow. If it does not have sunlight, then it will die (37)	5	M

HA4- Second problem-solving scenario

Predictive statements	Explanation statements	B	L
I think [the plant] would weigh less (1)	When you put water in the soil, it waterlocks and water makes [the plant] heavier (4)	3	L
	[the soil] socks the water up (6)	3	L
	[the plant] has eaten the water (8)	4	S
	[The roots] sucks the water from the soil (9)	1	S
	[Water] goes to the leaves and it s probably evaporated from the sun (10)	5	M
[The plant] will still grow because the bag is at the bottom of the plant and tied tightly (12)	The plastic bag helps the water evaporate (14)	2	S
	The plastic bag is insulating to make it hotter inside. Water will evaporate and then it will turn from water vapor to water condensing on the sides of the bag (16)	5	M
	[water] condenses and falls along the edges of the bag or it may go right down to the earth. It will go underneath the pot and [the plant] will use it (23)	5	M
The heat will eventually kill the plant (29). Before tht, it will shrivel up a bit because of lack of water (30)	Because of the sunlight, evaporating all the water (31)	5	M
	People water the plants a lot (32)	4	S

AA1- First problem-solving scenario

Predictive statements	Explanation statements	B	L
I think the plant will die (1)	light is not getting to the root area (2)	2	L
[the plant] will probably die slowly, it just wilts (3)	plant grows when sunlight is coming all around it (4)	1	S
	If there is not much sunlight the plant will die (5)	2	S
	[the root] lives in the soil, the soil doesn t have the light (6)	3	L
leaves soak up light and bring it down to the roots (7)			
[the plant] will wilt since there is lack of water (9)			
At the opening, the light source, the light will get at the bottom of the plant (10)			

AA1- Second problem-solving scenario

Predictive statements	Explanation statements	B	L
Water will vapourize onto the sides of the bag (2)	Plastic bag will stop the heat from leaving, it will block it (3)	1	L
	sun is giving out heat; the plastic bag will hold the heat in (4)	1	S
	heat will make the moisture evaporate (5)	2	S
	[moisture] comes from the soil when you water the plant (6)	2	L
I believe the weight of the plant will go (7)	Moisture leaves the pot. It just evaporates, it s not there anymore (8)	2	L
[Evaporated water] will just stay in the bag (9). When the plant need water later, it will soak up wht is in the bag (10)	[plant soak up water] through the stem (11)	1	S
	into the leaves (12)	1	S
	maybe evaporate off the leaves later (13)	1	L

AA2- First problem-solving scenario

Predictive statements	Explanation statements	B	L
[the light] hit the plant and the plant will grow bigger (2)	With most plants and some plants, they need light to grow (4)	1	S
	if it s a plant that needs light, then it will grow bigger (5)	1	L
the pot will be getting too small for the plant (6)			
The light goes in and the plant starts getting greener (7)	If [plants] are able to photosynthesize, then their leaves turn green (10)	1	M
	chlorophyl has something to do with the leaves being green (10)	1	S
Where there isn't that much light, [the leaves] start t turn brown (8)	Not much moisture might be o getting in, then they start to turn yellow, that s means they are dying, so they ll fall off the plant (13)	1	L
	If plants don t get moisture they will all dry up (15)	1	L
If it s a plant that needs a lot of light, then it will not survive (19)	A plant needs a lot of light; it will die with no light. A plant that doesn t need light it doesn t hurt to add any light to it, but it won t die if it doesn t have any light (20)	2	S
If it s a plant that does not need that much light, it will get bigger (22)	The stems will start getting bigger, taller and branches will start coming out (23)	2	S
may have to change [the plant] to a bigger pot (24)			
The plant may get too big for the box (25), will start squishing the leaves around the edges [of the box], it will just open up the box (26)	It won t have any where to grow, so it ll start bending over the sides (27)	2	L
	[it will bend] whichever way the box will make it go (28)	2	L
Part of the plant may start coming out on the sides, here [at the left opening], and the right side (31)	The leaves will grow and it will grow another stem. As more leaves will grow there will be moore stems (32)	2	L
	Because the sunlight is shining in these openings (33)	3	S
	will make the plant greener and might get bigger than the rest of the plant that is not [getting the light] (34)	2	S
	This part [without sunlight] will start turning grey a bit (36)	2	L

AA2- Second problem-solving scenario

Predictive statements	Explanation statements	B	L
[The plant] will weigh less (1)	condensation gets in the bag, it won't leave much [water] in the soil, so [the weight] may be less than when it started (2)	5	M
	The condensation that settles on the bag gets back to the bottom. That's where the plant is getting it's supply of water (3)	2	L
I think the plant will weigh less (4)	The condensation will not be as much. If you did not have a bag around it and you pour water [into the pot], there will be more and more weight than having a bag and having the condensation (5)	2	L
Water goes up the roots and helps the leaves grow (10), and then goes out as oxygen (13). We breath it in and then breath out CO2, and [the plants] take that in (14)			
I think the plant will weigh less (15)	the condensation will be less water than if the bag wasn't around it (16)	2	L
I think the plant may weigh equal (17)	the water from the condensation stays in the soil, [the plant] sucks it up (18)	2	S
	[water] goes up the roots and the stem (19)	2	L
	then comes out as a gas and goes in the air (20)	2	L

AA3- First problem-solving scenario

Predictive statements	Explanation statements	B	L
[The plant] will keep growing, but grow at certain angles (2)	[The plant] has got moisture [in the soil] (3)	2	L
	The plant is always turning towards the light (4)	1	L
	moisture helps [plants] grow if the moisture will stay nice and soggy (5)	2	L
	[moisture] will bring out more carbon dioxide or oxygen. The oxygen will go in the air which will bring more carbon dioxide, which will start breathing the water (7)	1	S
	[the plant] has got moisture going through the stem (8)	1	S
	sunlight remains in the moisture (9)	2	L
	some plants can use light and some plants cannot (11)	1	L
	this is a plant that takes light, I think light will help it (13)	3	M
Each leaf will start to grow bigger and wider (14)	with the light coming in, the leaves will start coming out (15)	3	S
[The leaves] will start to get bigger (21)	If you had just enough light, [the plant] will grow (23)	1	S
	You are going to give the plant too much light (22)	2	L
	It's giving the plant enough light but not enough to keep it growing (24)	4	L
	If you have enough light, the plant will be full (26)	3	L
	You can't really keep a plant in a box (27)	2	L
	In the upper opening, the plant will get light, but if you had full light, each area will break out instead of just a little [leaves] at the top (28)	3	L
[The heat] keeps the soil moist (32)	If there was no sunlight, no tree will actually grow (33)	2	L
	you need mostly sunlight to keep the soil moist along with the water (34)	2	L
	light will give enough heat, which will stay in the stem and the leaves (36)	3	L
Some of the leaves may start dying (39), the middle stops growing, the leaves will turn brown and start to fall off (42) It's growing [near the bottom opening] and start to get bigger (40) and it s growing near the top opening and will give it bigger leaves (41)	You got the area where the light is coming in, plus you have the sun in the pot to keep it moist (43)	2	L
	if it was in a dark room, it will surely start dying without sunlight and moisture (44)	2	L
	I do believe that this plant does need light (45)	1	L

AA3- Second problem-solving scenario

Predictive statements	Explanation statements	B	L
The air died; each day it will go on, it will all disappear (2)	you cannot keep air in a bag all the time because it will start being ruined (3)	2	L
	[the plant] has got a lot of moisture; it comes in and its trying to go up (4)	2	L
[the moisture] will go up the plant to the edge of the plastic bag and sits in that place (5)	[the moisture] comes up and then it just spreads out and tries to go back [into the soil] (7)	2	L
	Not all the moisture is going to go up through [the stem] to the top of the plant (8)	2	L
	most of [the moisture] will come up [to the top of the plastic bag] where it is tied to the plant (9)	2	L
	If you take the bag off, [the moisture] will go straight up [along the stem] (10)	2	L
the moisture will go right to the soil and stay there (11)	I am just taking a guess (12) just saying something through my head (13)		
not every part of the moisture goes in [through the stem], because the moisture can go up through the air (15)	if you take the bag off, the moisture can go up; but if you keep the bag on, the moisture is just going to hit [the plastic bag] (16)	2	L
[the moisture] goes in each stem; it will go to the leaves and keep them healthy (17), keep them strong instead of flaky and fall off(18)	I think moisture goes in the leaves and stays in the stem. It will go in, and if it builds up too much, it will go back down and then it go back up again (19)	3	S
The plastic bag will sag a little (20)	I am not sure if the air can get out; it will depend on how tight the bag was sealed (21)	2	S
The plant will still grow, no doubt about that (23)	The bag is not stopping anything from going up the stem (24)	2	S
	the moisture mostly goes in the stem and out to the leaves (25)	1	S
The sunlight coming in, helps it grow, cause it is a clear plastic bag (28)	If it is a clear plastic bag, moisture will go through; it will keep the bag warm (30)	1	L
	Where you put a plant depends on how much moisture you are going to to use. You put it in front of the window on a nice sun shiny day. The sun light goes right through the plastic bag (33)	3	L
	dark [plastic bag] will attract the heat and keep [the bag] warm (35)	1	L
	light plastic bag let the sun shine still come through to help the plant grow. Without sunlight the moisture will just crumble up. But the sun light keeps the water going, it is trying to keep it there as long as it can (38)	3	L

AA3- Second problem-solving scenario (continued)

Predictive statements	Explanation statements	#	L
[the plant] can lose weight, or it may gain (41) Maybe it will even gain weight beacuse the sun comes in and make the soil harder (46)	the soil will start getting and start getting moulding up (42)	2	L
	The moisture will start going in the plant, but it can t stay in the plant, it will have to disappear somewhere (44)	3	S
	The moisture goes up along the stem, plus the sunlight coming in, so it will keep the heat (48)	1	L
	the water and the moisture mixed together, so there will be no more water (49)	1	L
At the bottom of the bag, its soggy, it s like mud (51)	the pots are made of cement stone; some of them have the hole [at the bottom] (52)	1	L
	[the water] will come out of the bottom, you d have a mud batch (53)	2	L
[the platn] will gain weight and then it will lose it. Right now it is gaining weight (55)	Sunlight keeps coming in, plus inside there is air (56)	2	L
	The water will keep the soil nice and hard, water helps the soil to keep it nice and light (57)	2	L
	[by the end of the week], all the moisture will go up the stem into the leaves (58)	2	L

AA4- First problem-solving scenario

Predictive statements	Explanation statements	B	L
[The leaves] will die of fall off (3)	The leaves are in the middle here (4)	2	L
	'hey are not getting any light (2)	2	L
If the plant does not get enough waterm it will die (7)	water gives [the plant] minerals and just feeds them (8)	1	L
The leaves that are getting light will stay green (10)	Sunshine gives [the plant] chlorophyl (11)	1	S
	sunlight keeps [the plant] growing (12)	1	S
	[the leaves] that are not getting light will change colour, turn brown or just be plain white (14)	2	L
	without chlorophyl [the plant] kind of dies or just pulls away. It just dries up (15)	1	L

AA4- Second problem-solving scenario

Predictive statements	Explanation statements	B	L
The plant would weigh the same (1)	The bag is around the stem so the perspiration will collect on the plastic and it will just fall back onto the soil so it will just go in a cycle (2)	2	L
[water] will soak into the stem that is covered by the bag (9)	[the stem is] like a sponge (11)	3	L
[the plant] might lose a little bit of weight (13)	[water] will go up the stem and go up the leaves (12)	2	S
	that's how leaves get fed (14)	1	S
	the stem absorbs [the water] or the heat absorbs it (16)	2	S
[the plant] is going to lose a little [weight] (18)	the sun absorbs some of the water from the leaves, and it just gets more of the water through the soil (17)	4	M

AA5- First problem-solving scenario

Predictive statements	Explanation statements	B	L
I think [the plant] will wilt, I don't think it will grow anymore (1)	It doesn't have that much light (2)	3	S
	[plants] take in light and they change [light] into chemicals or something like that (3)	2	L
	light is the energy	1	S
the light is coming in here, it can't grow real straight up, but it will grow out of the box (7)	it's going to go straight up until it hits the roof (8)	2	L
	the plant won't be string enough to go through the box (9)	2	L
[the plant] grows kind of straight (12)	because it has the light coming from the two openings (13)	2	L
[the plant] might grow, starting another [branch] (15)	there probably is not enough room for all the roots in there, so they might come out and start forming another plant (16)	2	L
	[the plant will not grow] as fast because it does not get all the light that the tree need because it is inside [the box] (18)	3	S
some of [the plant] kmight come out of the openings (19)	[tne plant] needs more room to grow, so it will probably go to the light (21)	2	L
	if the box is full of vines, it needs more room to grow (22)	2	L
	[the plant] will grow out because it needs the light to survive (23)	1	S
	A plant usually grow towards the light (24)	1	S
	if there's no direct [sunlight], the plant just goes straight up (28)	2	L

AA5- Second problem-solving scenario

Predictive statements	Explanation statements	B	L
[The plant] will grow (1)	[The plant] can get light (2)	2	L
	the bag around the plant is sealed tightly to nkeep the moisture in (2)	2	L
	we water the plant, that is where moisture comes from (3)	2	L
	it will get hot in [the bag] because of the light (4)	2	L
	plants need minerals in the water to grow (6)	1	S
	[without moisture] the soil will become hard like a rock and the roots will not be able to travel, it will be too hard for the roots to push through (7)	2	L
	[the roots] feed on water and bring it up to all the different parts of the plant (9)	1	S
	[water] goes to anywhere that the plant needs, some plants can store water inside the leaves for a long time (10)	1	L
	water can be [in the leaves] or just stay in the roots if it isn't needed (11)	2	S
I think [this plant] will store water in the roots (12)	[the sun] can dry out the leaves fast because the water can evaporate from [the leaves] (14)	2	L
	but cactus has a hard shell so the sun cannor get at the water at once, so they cannot store water that way (15)	1	L
	why you have to water a plant is because water evaporates fast (16)	1	L
[the plant] would weigh more (18)	[the plant] will weigh more because it keeps growing (19)	2	L
	[the plant] will not weigh that much more, but it will (21)	2	L
some of the water will go in the roots and go up to the leaves, and then the sun will take that away (30)	the top of the plant that is not in the soil needs water to live, too (26)	1	S
	there might be water in the [leaves] of the plant (25)	2	L
	the leaves might become dry in a week (27)	2	L
[the sun will take the water from the leaves, but it will not be able to evaporate because of the plastic or the cover (32)			
[the plant] may be all shredded up (33)	if [the leaves] keep bringing all the water up, all the water will be gone because the sun will have evaporated it away; pretty soon [the plant] may run out of water so there will not be enough to feed the leaves and they will dry up (37)	2	L
[the plant] will not be completely dead, but it may be pretty sick (38)			
the weight of the plant will be equal (39)			

Appendix E

Students' Sources of Prior Knowledge

	teacher	siblings	parents
HA1	all the teacher did was put notes on the blackboard, and we copied that	none	none
HA2	[teacher] will [tell us] to find the book or material in the library	none	my father s times teach about scien
HA3	[teacher] gave us a lot of books that we could go and figure out what we were to do	[older sister]	my mom is a nurse and m dad teaches science, he a real help they challe me to think things on m
HA4	[teacher] takes the information and just gives it; she asks the librarian to get books together for us	none	they encour me to learn ask my mom [I do proje she would t and find so thing [for

	television	magazines	books
	I really like science nature shows, like National Geographic	[occasionally I] read Discover	I like [science magazines]; I use the reference library when I have a project for school
some- :h me ınce	usually the ones about animals	read [science magazines] only about airplanes and cars; have National Geographic at home	[read science books from the library] when I have a science project in school; we have encyclopedias at home
a my ɛs ıe's lp; lenge ık out my own	I watch nature shows; animal shows	read National Geographic, use for reference in science projects; used get Owl	read seven or eight books a week, on anything, but not always science
ırage :n; I ı when jects], try some- : me]	I watched the Nature of Things, but the topics are [usually] not for children	have National Gepgraphic, Owl and have read Equinox, but it ıs too advanced	I use books from school library; have [a lot of] science books

	teacher	siblings	parents
AA1	[teacher] just gives us the lessons in class; she does not refers us to other source	none	none
AA2	when we did a unit on eco-system, [the teacher] told us to get books from library to look things up	my sister some-times tells me some things about plants	[my parents] talk to me about animals and plants
AA3	some of my teachers do not [encourage me to go to the library to read more; in my junior school, [the teacher] would say "that is enough". The teacher gives assignments, if we get it all right, that means we are understanding it	I have asked my brother [about science], but I have never learned any-thing; I never did anything with what he said to me	none
AA4	sometimes the teacher [refers us to explore things]; some-times he does, not a lot	none	none
AA5	we haven't done that much in science; we have to use the text book	my younger [siblings] know a lot more about dinosaurs they make fun of me	[my parents] encourage me t learn; my mom' not into science at my level

	television	magazines	books
	occasionally watched Wonder Struck	none	I read astronomy books; about once in two weeks, I go and look around for books about astronomy or fish
s	I watch Owl sometimes	read Owl and National Geographic about animals	I read animal books and that is about it
	I have watched Wonder Struck; I'd watch if there is something I like	I didn't read anything about science in [the magazines]	I read fantasy books, or adventure books
	[watches science shows] when there is nothing else on television	do not have any science magazines	I usually read story books
to n's ,	I've watched Wonder Struck a few times; only when there is nothing else	depends if I have time, I read about fish [in magazines]	don't usually read science books

Appendix F

Students' Attitude Toward Using Prior Knowledge

Interview 2 with HA1

Exp: Do you feel that in learning about science, or any other subject, that it is important that you make use of what you already know?

HA1: Yes.

Exp: Can you tell me some of the ways that you make use of what you have already learned?

HA1: Well, yes. Like in tests or anything, well this, I already knew that it reaches for sunlight, photosynthesis. So, I guess I can take a guess, but I don't have to.

Exp: I see. If you have learned something about the way in which plants grow, let's say, from television program, would it help you? How do you relate what you saw on T. V. with something that you may have learned in class about plants? HA1: Well, I don't know. I didn't really see anything like that on T. V.

Exp: The show's not about plants?

HA1: No, usually the show is about animals.

Exp: And do you often think about the animal shows that you have seen on television, and relate it to your biology/science lessons, to make your classroom learning more relevant?

HA1: I don't know.

Interview 2 with HA2

Exp: Do you feel that in learning about science, or any other subjects, it is very important when you make use of what you already know?

HA2: Yes.

Exp: Can you tell me in what ways it would help?

HA2: Well, if you already know something, then you can look up something that you hardly know to get more detail.

Exp: O.K. Does it mean that if you already know about a subject, then you will simply know more about it by learning more about it?

HA2: Yes, you already have a background in which to work at.

Exp: How does having a background knowledge help? Do you know?

Ha2: Well if it was something that was really buried deep in of your understanding, you already know something about it, it would help you research it.

Exp: O.K. I think it's basically all the questions that I have.

Interview 2 with HA3

Exp: Do you feel that in learning about science in your natural environment around you, do you feel that in learning about these things, is it important that you make use of the knowledge and theories that you already have?

HA3: Yes, I think it is because we get more knowledge as we go along and our past experience and knowledge can also help us when we're learning new stuff. Because if you know some from like before, in the past, then it's going to come out sometimes, at least once in a probably a year, it's going to come up separate. What you were taught in a certain grade is going to come up in another grade. In a higher grade, they're going to ask you about this stuff. And it's really good to know it because if you don't it's pretty hard to relate to what we're talking to. And if you do know it, then it's really nice because then you have it right there and you know what they're talking about and it's really easy to understand what they're talking about.

Exp: So it makes it easier to understand new information.

HA3: I think so.

Interview 2 with HA4

Exp: You have a lot of science information from different books that you read, magazines from you mom and your dad. You gather all these informations from all the sources and people around you. Then in your learning in the classroom, do you alrways think about what you already know, and you try help you understand your lessons?

HA4: If you think about what you already know, it will make it a lot easier. Then you can look for the information. You won't have to look for as much and write down as much.

Exp: Do you find that it is helpful?

HA4: Oh it's helpful, yes. You know it's sort of boring when you have to go through it so many times. Again and again.

Exp: Do you think that with practice it would become automatic?

HA4: Yes. Maybe. Our teacher is trying to get us ready for high school. And giving us good ways to study and essays, stuff like that.

Exp: I see. Can you tell me, from your experience, why using what you already know helps you learn better?

HA4: I just know it works for me.

Interview 2 with AA1

Exp: Do you feel that learning in school, it helps you learn new things when you can make use of what you already know?

AA1: Yes.

Exp: Can you tell me in what ways it would help?

AA1: Well, if we use what we already know and put it with stuff that we're learning now, we might understand it better.

Exp: Yes. Why do you think that's so?

AA1: Because, well, if you know something, well if you learned it last year, and then you're sort of forgetting about it now and you learn something new, and it's on the same subject, you might know more about it.

Exp: O.K. Do you usually make use of what you know when you're learning new things?

AA1: Most of the time.

Exp: Can you give me an example of something that you have done recently, that you have try make use of old knowledge when you are learning something new?

AA1: Um...I can't think of anything. I don't usually already know something. Usually I learn new things that I don't know.

Interview 2 with AA2

Exp: Do you feel that in the learning situation, when you're sitting in class and learning about a subject, that it's important that you make use of what you already know in order to learn new things.

AA2: Yes, because if you know something, that might bring more things to your mind about more things that you're learning about.

Exp: I see. It it something that you often do? That is, try to add what you are learning onto something that you already knowl

AA2: Say, we have, like we just learned something and say you don't know what it is, like how it happened or whatever you remember from your how you learned it before. When you learn about it again, then you can remember more.

Exp: I see. Can you think of other ways that your old knowledge can be useful?

AA2: No, not really.

Interview 2 with AA3

Exp: You know when you're learning things in school, do you feel that it would help you learn when you make use of what you already know?

AA3: Um...

Exp: Did you understand my question?

AA3: Kind of and kind of not, really.

Exp: O.K. Let's say you learned something from your brother; he told you something about dinosours. Then your teacher is going to talk about dinosaurs in class next week and when you're sitting in her class, and learn about what she presents about dinosaurs, do you think it helps when you can remember what you've learned from your brother?

AA3: Yes. It would...uh...

Exp: Can you explain how it would?

AA3: Well, if my brother has taught me something about one specific dinosaur or many and she brings up something, it's a small one, with spikes on its back, it really is tough. And if my brother has told me, and I can remember most of what he told me. Because maybe then I wasn't paying it really attention, yes, it really would help me. Then I'd remember what he said plus what she said. So I'd have two combining locked in my head. So I would remember. It really would help me.

Exp: Yes. Does it happen often in your learning? These situations?

AA3: Like if my brother has taught me something and it comes out in the science class?

Exp: Or if you've read something and it comes up in class and you say, "Ha, I know that."?

AA3: Yes, it does.

Exp: And it makes you more exited. Does it happen often?

AA3: Yes. Well not really often, but it's happened the odd time when we're learning. But then the thing is going, I wasn't expecting it.

Exp: I see.

AA3: It would help me, but it doesn't basically happen every time.

Exp: O.K.

Interview 2 with AA4

Exp: I want to ask you if you feel that in learning about science or learning in general, whether, it is important that you use what you already know in order to learn more?

AA4: Yes.

Exp: Can you tell me in what ways it can help? For yourself?

AA5: If you know in one certain subject and then the teacher can teach you more about it like, like carrying on from where you learned.

Exp: I see. And does that help you?

AA4: Yes.

Exp: When you're learning in the classroom, do you pay attention to that? Are you always reminding yourself of what you already know and try to bring in your new knowledge? Do you understand?

AA4: No. Not really.

Exp: O. K. Let's say you have studied dinosaurs in grade one or grade two, and your teacher now will give you a lecture on dinosaurs on Tuesday, do you consciously try and remember what you already know about dinosaurs and to relate the information that you learned in grade one to the ones that you are learning now?

AA4: Yes.

Exp: You do.

AA4: Yes.

Exp: O.K. Can you think of an occasion that you did and tell me a little bit more? A little bit about it?

AA4: No, I can't really remember.

Exp: No? So you just know you do it.

AA4: Yes.

Exp: O.K. I think that's basically it. I covered all the questions that I had written down for you.

Interview 2 with AA5

Exp: I want to ask you if you feel that in learning, in general, is it important that you make use of what you already know? ....Um....Do you understand the question?

AA5: No.

Exp: Let's say, you learned from your brothers and sister, something about dinosaurs. If your teacher was going to give a lecture next week about dinosaurs, do you think what you learned from your brothers and sister, is it going to help you understand and learn what you would learn in class?

AA5: Maybe just a little bit. Because I just know the basic things like the meat eaters, plant eaters, stuff like that. Not much, but I think it would help a little.

Exp: If it would help a little ? Can you think of what ways in which it would help.

AA5: Well, I might have heard of the names of the dinosaurs. You have so many dinosaus with all those different names. That might help because they have books there with different pictures and all that basic information.

Exp: O.K. That's all the questions that I have for you today.

UTILIZATION OF PRIOR KNOWLEDGE
IN SOLVING SCIENCE PROBLEMS:
A COMPARISON BETWEEN
HIGH-ABILITY AND AVERAGE-ABILITY STUDENTS

by

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Department of Educational Psychology
and Counselling

A thesis submitted in conformity with the requirements
for the Degree of Master of Arts
in Educational Psychology
McGill University
March 1989

High and Average Ability Students' Utilization of Prior Knowledge

Abstract

This study examined the use of prior knowledge to predict the solution to science problems. Four high-ability and five average-ability grade 8 students participated in the study. Three science lessons were implemented to assess the effects of teaching the students how to access and utilize their prior knowledge in making predictions. The way in which students used prior knowledge before and after these lessons was evaluated using qualitative and quantitative methods. Results suggested that there were differences in the way the two groups of students organized and utilized their prior knowledge. The high-ability students exhibited well-integrated prior knowledge, and readily utilized their prior knowledge to produce high-level cognitive behaviors. Relatively, the prior knowledge of the average-ability students lacked integration, and these students were unable to translate their prior knowledge to high-level cognitive behaviors. These findings suggest that the two groups of students differ in the level of integration of their prior knowledge, and the ways in which they utilize prior knowledge are also different. This may be related to their differential ability in predicting solutions to problems.

Résumé

L'utilisation des connaissances antérieures dans la prédiction des solutions de problèmes scientifiques a été examinée dans cette étude. Neuf élèves du deuxième secondaire, soit quatre ayant des compétences académiques supérieures et cinq ayant des competences académiques moyennes, ont participé à l'étude. Trois leçon de sciences ont éte ensignees afin d'evaluer les conséquences d'enseigner aux élèves comment utilliser leurs connaissances antérieures pour predire les solutions de problèmes. Des analyses qualitatives et quantitatives ont été exécutées. Les leçons de sciences n'ont pas eu d'effet sur la façon dont les élèves utilisaient leurs connaissances antérieures avant et après les leçons. Les analyses ont montré cependant qu'il y avait des différences entre les deux groupes d'élèves dans l'utilisation et l'organisation de leurs connaissances antérieures. Les connaissances antérieures des élèves ayant des compétences superieures étaient bien intégrées, et étaient utilisées facilement lors de comportements cognitifs de haut niveau. Comparativement, les connaissances antérieures des élèves aux compétences moyennes manquaient d'intégration. De plus, ces élèves étaient incapables d'utiliser leurs connaissances antérieures lors de comportements cognitifs de haut niveau. Ces résultats suggèrent que les deux groupes d'élèves procèdent différemment pour utiliser leurs connaissances

antérieures. Ceci pourrait être relié aux différences dans leurs capacités de prédire les solutions de problèmes scientifiques.

Acknowledgements

Sincere appreciation is extended to the students of Darcel Senior Public School (in Malton, Ontario) who participated in this study, and to Ms. Margaret Draper for accomodating the procedures of this study and conducting the science lessons. Their cooperation was paramount to the procedures of the data collection. I am also thankful for the support and scholarly advice of Ms. Francis Halliday.

I wish to express my deepest gratitude to Dr. Lila Wolfe, who provided expert advice and guidance without which this thesis would never have materialized. Her penetrating suggestions and recommendations were of inestimable value to me. Acknowledgement also goes to Dr. Bruce Shore for his encouragements and contributions that enabled me to conceive and execute this thesis. His advice and editorial expertise helped me immensely in the writing of this thesis.

Many thanks to Marie Christine Busque her assistance in the French translation of the abstract. Her friendship and emotional support are crucial elements of my graduate career.

My warmest appreciation is extended to my spouse, Ian, whose understanding and devotion provided me with warmth and vigor at times when my confidence waned. His humor, inspirations and sagacity were powerful enlightenments which enabled me to surpass all the obstacles.

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CHAPTER 1

Rationale for the Study

Introduction

This study compared the ways in which prior knowledge was accessed and utilized by high-ability and average-ability students to predict the solution to science problems.

In order to make such a comparison, both groups of students were given a science problem-solving scenario and asked to make a prediction about the outcome. Their responses were analyzed and compared. Subsequently, the students were exposed to three science lessons in which a teacher explicitly taught them ways of accessing and utilizing prior knowledge in problem-solving. Finally, the students were assessed again, and given another science problem in which they were asked to make a prediction. Their utilization of prior knowledge was again analyzed, and compared with their performance before the science lessons so that the effect of the intervention could be inferred.

The following sections outline the theoretical and practical justification for this study. Although research in the domain of problem-solving is abundant, the link between prediction-making and utilization of prior knowledge is yet unexplored. This study will attempt to provide a conceptual link between these concepts. In addition, the practical implications of effectively using prior knowledge in problem-solving activities will be discussed.

Theoretical Justification

This study arises from three interests: (a) the role prior knowledge in problem-solving, (b) the processes of problem-solving and prediction-making in high-ability and average-ability students, and (c) problem-solving in the context of science learning. These will be explored further and related in the sections which follow.

Prior Knowledge and Problem-Solving

The theoretical link between prior knowledge and prediction making becomes apparent as one of the processes of problem-solving. Thus, one must begin by understanding the interrelationship between knowledge acquisition, problem-solving and prior knowledge.

Knowledge acquisition and prior knowledge. Prior knowledge simply refers to information that one already has stored in memory. It facilitates the acquisition and accumulation of new knowledge (Adams & Collins, 1979; Dirkes, 1985, April; Glaser, 1984). It provides an anchor for the learning of new experiences (Ausubel, 1968) because new ideas are learned and retained most efficiently when contextually related ideas are already available in one's memory (Langer, 1981, 1982). Nonetheless, learning does not take place merely by adding new knowledge to prior knowledge. It involves an interactional process where new knowledge is incorporated and organized within the preexisting framework of prior knowledge, potentially resulting in changes in that framework as well (Adams & Bruce, 1982; Hewson & Hewson, 1983).

The study of prior knowledge has been elaborated in the domain of text comprehension. Effective tapping of prior knowledge in a contextually related area results in more successful comprehension and recall of knowledge (Anderson, 1976; Anderson & Bower, 1973; Langer, 1982). Moreover, prior knowledge also plays an important role in facilitating the understanding and interpretation of novel information and leads to better comprehension of the materials (Langer, 1982, Langer & Nicholich, 1981).

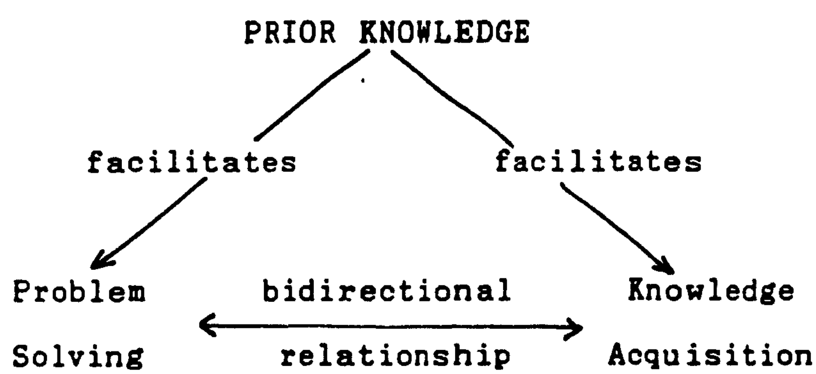
The role of prior knowledge has also been investigated in other areas of learning, such as scientific problem-solving. Hewson and Hewson (1983) investigated the learning process of a group of grade 9 students during science lessons. The result confirmed the notion that prior knowledge may facilitate subsequent learning situations.

Knowledge acquisition and problem solving. In relation to knowledge acquisition, it is useful to think of the process of problem solving as a type of learning that facilitates the accumulation of knowledge (Newell & Simon, 1972, p. 814). Problem-solving includes the evaluation of what one already knows (prior knowledge) in order to arrive at a state of knowledge that is new. The novel material will then be incorporated into one's preexisting framework of knowledge and result in the acquisition and accumulation of knowledge. Such is a cyclical process in which the accumulation of knowledge not only facilitates problem-solving, but it is also facilitated by engagement in problem-solving tasks.

Prior knowledge and problem-solving. Prior knowledge, in the context of problem solving, is defined as the source of information available to an individual from which the execution of solutions could be made possible (Newell & Simon, 1972). It includes information such as (a) task instructions that are provided, (b) knowledge or information that an individual has gathered through previous experiences with an identical task, or one that is analogous, (c) knowledge or information that is in the individual's long-term memory that can be combined with information in the given task to yield a solution, or (d) knowledge or information stored in long-term memory that has substantial generalizability and can be applied to a wide range of tasks (p. 811).

Taylor (1978) captured the relationship between prior knowledge and problem-solving abilities by stressing the importance of "forecasting" and "decision making" where one objectively organizes prior knowledge in such a way that a rational prediction could be made. Gallagher (1985) suggested that problem-solving could be explained as a convergent thinking process in which one takes a large number of facts or associations (prior knowledge, either given in the problem, or stored in one's memory) and puts them together in a certain predictable combination to reach a possible right answer (p. 277).

The relationship between prior knowledge, problem-solving and knowledge acquisition can be conceptualized as follows:



Ability Level and the Utilization of Prior Knowledge

The role of prior knowledge might be important to understanding the enhanced acquisition of knowledge by high-ability learners. One might attribute their intellectual superiority to their rich source of prior knowledge and the framework in which it is represented (Chiesi, Spilich, & Voss, 1979; Voss, Blais, Means, Greene, & Ahwesh, 1986). Dirkes (1985) reported that high-ability students have varied cultural experiences and rich memory storage, and have thus accumulated an enormous body of knowledge. Their overall intellectual superiority is likely to be due to their ability to use what they already know as a foundation to future learning. This ability is fundamental to "higher level thinking" (Bloom, 1956) where one progresses beyond acquisition and comprehension of information to make further application of the prior knowledge. Thus, it is important to examine the ways in which high-ability learners access and utilize their prior knowledge in learning situations.

High-ability students are commonly observed to be superior in their problem-solving behavior (Ward, 1980). A recent thesis by Coleman (1988) examined problem-solving performance by high- and average-performing physics students. In their protocols, the more able students made more frequent references to their prior knowledge;

contrarily, the less able students made more references to information given in the presentation of the problems. This was consistent with current theory distinguishing "expert" and "novice" performance in such tasks (Glaser, 1985). However, these studies did not explain how the prior knowledge was used. Including subjects of different ability levels allows the present study to examine if part of the success of more able students is the ability to make predictions based on their prior knowledge. Are there any qualitative differences in the ways that high-ability learners use their prior knowledge when compared with average-ability learners? Do high-ability students use their prior knowledge in a way which facilitates high-level cognitive behaviors?

Problem-Solving in Science

Problem-solving is an important activity in science education for three main reasons. First, much of everyday experience in our environment can be explained by naturally occurring scientific phenomena, and the understanding and exploration of our environment includes a series of problem-solving situations.

Second, in science, the knowledge base is very large and constitutes an abundance of concepts, generalizations, principles, as well as skills. The process of problem-solving can aid in the construction of a network of relationships among concepts and generalizations. Hence, such a network of knowledge can be stored in long-term memory and be readily retrieved when future problem-solving situations arise.

Third, when students observe their teacher explaining a science problem, they often do not witness the thought processes that lead to the solution of the problem; teachers tend to think through the problem, privately, before presenting the explanation and solution. The students may then fail to conceptualize the process involved in arriving at the solution. Therefore, in science learning, it is crucial for students to have first-hand problem-solving experiences (Nickerson, Perkins, & Smith, 1985).

It has been observed that, although students have accumulated a lot of knowledge and information during their science lessons, they were unable to use their knowledge in novel problem-solving situations (Gunstone & White, 1980). Students were particularly inadequate in identifying the relevant knowledge that could be applied to specific situations and lacked the ability to apply their scientific knowledge and skills in even moderately novel situations (Olson & Russell, 1984). These observations relate to the science learning environment of elementary and high school students. The science lessons were predominantly concerned with the accumulation of science vocabulary, while classroom discussions and first hand investigations had been deemphasized.

It is important for educators to ensure that students not only have an accumulation of scientific knowledge, but also the ability to utilize that knowledge. Problem-solving activities during science lessons can be an effective way to relate these two objectives. Problem-solving scenarios can also provide insight into students' level of understanding of scientific phenomena. In addition, the types of processes which students of various ability levels use to solve a problem will also become apparent. Then, those processes that are characteristic of high-ability learners could be made explicit during classroom instruction in problem-solving.

Practical Justification

The practical application of this research would be concerned with teaching students how to use their prior knowledge. Research findings have indicated that high-ability students have rich sources of prior knowledge, and from the point of view of educational enrichment, teaching them to draw on their prior knowledge may further enhance their problem-solving performances.

A parallel and crucial question that emerges in this context addresses the value of providing similar enrichment for average-ability learners. Romey (1980) acknowledged that one of the objectives of education lies in the provision of opportunities for maximizing one's full potential. Therefore, students of various ability levels should be encouraged to optimize their development in high-level thinking, including rational analysis, systematic observation, and other processes associated with scientific thinking.

Others echoed the claim that if a curriculum is beneficial to high-ability learners, it should also be effective among average-ability learners. The basis of this claim lies in the assumption that mental abilities which the enrichment curriculum fosters, such as abstract reasoning skills and analytical thinking skills, can be developed in all students (Maker, 1982; Taba, 1962). It was suggested that average-ability students may require more time for learning the contents of a curriculum. Nevertheless, when the activities are paced appropriately, 80% of the average-ability students show a significant development in higher-level thinking skills (Bloom, 1976). Taba (1962) reported similar concern and developed a teaching model that nurtures analytical thinking skills by guiding students through a series of sequential intellectual tasks, and asking them open-ended, yet focused questions. Experimental evidence supported the contention that with the use of Taba strategies, students with average IQ exhibited growth in cognitive skills as great as those of high-IQ students.

The number of research studies that looked at enrichment for high-ability and average-ability learners in parallel is scarce. Those that have made such a comparison have generated evidence that enrichment programs for high-ability learners should not exclude its application to average-ability learners (Bloom, 1976; Maker, 1982; Renzulli, Smith, & Reis, 1981).

The present study focused on one aspect of enrichment: the effective utilization of prior knowledge, because of its intricate relationship with science learning, problem-solving, and knowledge acquisition. To date, no studies have been conducted to find out whether such instruction can be effective in helping students apply their prior knowledge in problem-solving situations.

This study was also instigated by concern about whether effective utilization of prior knowledge is a process that can be learned. High-ability and average-ability students were included in this study and their performance in problem-solving, before and after such instruction, was examined.

CHAPTER 2

Review of Literature

This chapter is devoted to a review of research in four areas that are pertinent to this study: (a) the application of prior knowledge in problem-solving and, specifically, in the prediction-making process for solving problems; (b) the comparison of high-ability and average-ability performance in problem-solving scenarios, with particular focus on the research that compared high-ability and average-ability performance in the use of prior knowledge; (c) the implications of teaching specific problem-solving strategies and the need for well structured instructional programmes; and (d) the importance of teaching students how to access and utilize their prior knowledge in solving science problems.

Use of Prior Knowledge in Problem-Solving

The role of prior knowledge in the process of problem-solving has received much attention in cognitive research. Various theories of problem-solving have alluded to the importance of using prior knowledge to aid in the solution of problems. Hayes (1981), Newell and Simon (1972), and Sternberg (1977) presented this concern from different perspectives.

From a pragmatic perspective, Hayes (1981) suggested that problem-solving could be approached by one of four methods: (a) trial-and-error, (b) proximity methods, (c) fractionation methods, and (d) knowledge-base methods. The trial-and-error method typically does not involve the use of one's prior knowledge because the problem-solver either does not have, or does not use, the available information gathered from prior learning situations (p. 30). However, the other three problem-solving methods are characterized by the use of prior knowledge in arriving at a solution. In the proximity method (p. 31), one would make use of prior knowledge in order to determine the most direct path co reach a goal In the fractionation method (p.35), the prior knowledge is initially available in order to break down a problem into subgoals, and then each subgoal is approached by using prior knowledge in a manner that is similar to that of the proximity method. Ir. the knowledge-base method (p. 39), one uses the prior knowledge stored in memory to guide the search for a solution. Therefore, one may conclude that prior knowledge is necessary for problem-solving situations, although the ways in which prior knowledge is used depend on the experience of the problem-solver.

Newell and Simon (1972) suggested that when solving problems, the problem-solver proceeds by a scan through information related to the problem that is readily available

(p. 811). This includes information stored in long term memory, that is, (a) prior knowledge and experience that are almost identical to the problem to be solved, (b) prior knowledge and experience that are analogous to that of the problem being solved, and (c) knowledge that can be substantially generalizable across a wide range of problem-solving tasks (p. 848). In other words, the successful execution of the problem-solving process is dependent upon the prior knowledge available to the problem-solver.

Sternberg (1977) reviewed a specific type of problem-solving behavior, namely, analogical problem-solving, and asserted that one cannot make an educated decision about something new without drawing a parallel with something old (p. 353). Clearly, Sternberg believed that in problem-solving, one of the ways in which a solution can be reached is by drawing a parallel relationship with prior knowledge or related experience that is readily available to the problem-solver. Furthermore, scientists and mathematicians have often reported that solutions to problems are arrived at after they have recognized analogies in information gathered from previous experiences (Halpern, 1987).

Understanding the intricate relationships between problem-solving and prior knowledge plays a special role in educational objectives regarding the nurturance of higher order thinking skills among learners (Bloom, 1956;

Gallagher, 1975; Torrance, 1970). The essence of higher order thinking is captured in the ability to transform old information to solve new problems (Gallagher, 1975, p. 233). Although content-specific prior knowledge is necessary for problem-solving, it is not sufficient to guarantee best performance (Brown & Campione, 1980; Greeno, 1980; Miller, 1962; Simon, 1980). The ability to utilize the content-specific prior knowledge is also of utmost importance (Barrows & Tamblyn, 1980; Wingard & Williamson, 1973).

This study thus responds to the concerns of problem-solving research and considers how different learners access and utilize their prior knowledge in problem-solving scenarios.

Use of Prior Knowledge in Prediction-Making

Prediction-making is an important problem-solving procedure in which the use of prior knowledge is particularly salient. In general terms, the prediction-making process guides the problem solver to anticipate coming events, and also the consequences of those events. This information then allows the problem solver to plan a course of action in attempting to arrive at a solution (Friedman, 1984, pp. 45-59).

The process of prediction-making is thus highly dependent upon the availability of prior knowledge. In order to make a prediction, the problem is first identified by carefully observing the events that are presented. The discrepancies between what is presented and the desired goal are examined (Dirkes, 1985; Friedman, 1984, p. 45). Subsequently, there is a search of memory for relevant prior knowledge (Friedman, 1984, p. 255) that may be applicable to the present situation. Prediction-making is, therefore, a process that requires the problem-solver to verify that the prior knowledge is leading towards the desired goal (Brown & DeLoache, 1978).

The availability of prior knowledge, however, does not guarantee that a sound prediction can be reached. The problem-solver must also have the ability to use the information appropriately so that a prediction that is likely to yield a solution can be brought about (Babbs & Moe, 1983; Bondy, 1984).

On the other hand, there is no empirical finding that addresses how prior knowledge can be incorporated and used in the process of prediction-making during problem-solving scenarios. Since prediction making is an important and unavoidable step of problem-solving, an attempt to teach effective problem-solving may be partially accomplished by discovering the ways in which prior knowledge can be effectively used to make predictions.

The present study was designed to investigate how prior knowledge can be used to facilitate prediction-making in problem-solving scenarios. There are two reasons for focusing on prediction-making. First, problem-solving may begin by making predictions, and second, prediction-making is one of the many processes of problem-solving where the use of prior knowledge is of particular importance. To date, there exist no research studies that specifically focus on investigating the processes of prediction-making. This study attempts to consider problem-solving by using prior knowledge to make predictions.

Comparing High-Ability and Average-Ability Learners in Problem-Solving Behavior

Contemporary studies of human problem-solving regard the study of differential abilities between advanced learners and average learners as critical in understanding the problem-solving process. Advanced learners are often superior problem-solvers, and thus, much of the research in this area examines the students with high scholastic abilties.

Ristow, Edeburn and Ristow (1986) observed that high-ability students are, generally, more self-initiated and internally motivated than their average-ability counterparts. This is inferred by their ability to engage in independent studies, whereas average-ability students typically preferred programmed instruction and discussion groups where they need to receive continuous feedback from others (Steward, 1979). These authors thus asserted the importance of self-directedness in learning as a critical characteristic for the development of superior problem-solving abilities.

Rogers (1986) cautioned against over-emphasis of students' learning style as a basis of distinction between high-ability and average-ability performance. In a review of current research concerning high-ability students, she argued that these learners are not using a unique brand of learning or thinking style, although their capabilities may be more pronounced in some of the dimensions. For instance, the high-ability learners are: (a) more able to analyze, synthesize and evaluate newly acquired information (Ward, 1980), and (b) more skilled in solving novel problems that require transfer of previously learned strategies and content (Scruggs, Mastropieri, Jorgenson & Monson, 1985, 1986). Despite this caution with regard to overall styles, there is mounting evidence of differences in the specific processes used by more and less able students (Shore, 1986; Sternberg and Davidson, 1986).

These assertions also supported Keating's (1976) analyses of cognitive behavior of high-ability and average-ability students from a Piagetian point of view. It was observed that grade 5 "gifted" students were performing at a more advanced level than grade 7 "average" students, and that the former advanced to the concrete operation stage more quickly. The author stated that these superior developmental patterns are attributed, for the most part, to the intricate interaction between the learner's ability to generate and retrieve information, and the ability to make use of the information that is generated.

Related to the generation and retrieval of information is the notion of memory. Much of the research has suggested that "gifted" learners have a high capacity for memory storage and, therefore, some researchers have extended this to suggest that higher capacity for memory enables an individual to have more capacity for performing higher-level, integrative components in a problem-solving situation.

Ludlow and Woodrum (1982) observed that in a multi-trial task, high-ability learners do not rely on the availability of feedback from previous trials because they are more able to remember them. Contrarily, average-ability students are more dependent on the availability of feedback for their success in the task. This finding suggested that memory capacity may play a role in problem-solving situations.

Other empirical evidence, however, has cast doubt on the effects of memory capacity on problem-solving situations. By manipulating the amount of information that one needed to solve problems, other studies found that there was no observable relationship between high-ability performance and average-ability performance (Holzman, Pellegrino & Glaser, 1982, 1983). Thus, there is no conclusive evidence to suggest that high-ability performance in problem-solving, or any other intellectual task, is distinguished by good short-term or long-term memory.

These controversies suggest that memory strategies, rather than memory capacity, may be more crucial for making predictions during problem-solving scenarios. In addition, the strategies which are used to structure the storage of knowledge in memory, and the strategies used for applying that knowledge in a problem-solving situation should be addressed (Jackson & Butterfield, 1984; Anderson, 1985, April; Anderson, 1985, November). Studies in this domain have introduced the use of strategies for rearranging, adaptating and transforming prior knowledge in general problem-solving situations (Dirkes, 1985, April).

The present study explores the ways in which high-ability learners and average-ability learners access and utilize their prior knowledge to make predictions in science. Specifically, the relationship between the organization of domain-specific knowledge and the level of thinking displayed when students make predictions during problem-solving scenarios will be explored.

Direct Instruction of Cognitive Skills

Studies that compared the intellectual abilities between high-ability and average-ability students typically were successful in identifying some superior characteristics of the high-ability students. However, many researchers were also alerted to the observation that high-ability learners often needed environmental support, such as training and enrichment, before they could excel. Benbow (1987, April) remarked that high-ability learners often have parents that are supportive and encouraging of their educational needs and goals. Supporting evidence was also inferred from the observation that although high-ability students are typically self-initiated in their learning habits, they too, require training and guidance in order to perform at an independent level commensurate with teachers' expectations (Ristow, Edeburn & Ristow, 1986).

Ludlow and Woodrum (1982) evaluated the effects of availability of feedback in problem-solving performance. They found that although average-ability students were, in general, more reliant on the availability of feedback, they were able to out-perform the high-ability students when feedback is available continuously. This observation was contradictory to findings of other problem-solving research.

The authors speculated that this contradiction may be due to the fact that high-ability students had not received any enrichment or special training to enhance their initial strengths. Therefore, it becomes doubtful as to whether superior cognitive abilities could develop spontaneously without special training. It has been argued that the only means of ensuring consistent and effective problem-solving performance is by providing practice and applications of the skills already mastered (Redfield & Rousseau, 1981; Seiger, 1984).

The methods by which specific skills should be taught are also controversial. Doyle (1983) proposed that indirect instruction should be used in the teaching of higher level cognitive processes to more able students because these learners have already mastered the necessary and basic knowledge structures and skills. In contrast, direct instruction, in which learners gain practice through a series of structured exercises leading to mastery of cognitive processes, are proposed as more appropriate for average-ability learners. The former is characterized by a laissez-faire approach (Gallagher, 1985b, p. 293) wherein learners search for new ideas with a sense of freedom to explore.

The use of a laissez-faire approach can be problematic because of the danger in assuming overall competence among high-ability students. Although the overall intellectual capability of the high-ability learners is superior to that of average-ability students, there are still tremendous variations within both groups, exhibited as strengths and weakness in various areas (Houtz, Rosenfield & Tetenbaum, 1978). Provision of direct instruction to high-ability learners can, therefore, be beneficial because it allows the opportunity for well-rounded intellectual development (Simon, 1980).

Researchers have developed various programs in response to the need for educational enrichment. In the past decade, many of the programs that were developed focused on the enhancement of problem-solving strategies and skills and the fostering of high-level thinking processes.

Baines (1984) highly recommended the use of IMPACT in the teaching of problem-solving activities. The program concentrates on six relevant procedures that are valued as highly relevant to problem-solving behaviors, that is, interpret, collect more information, look for possibilities, assess, change and test. IMPACT problem-solving begins by identifying the nature of a problem and the various possible sources of information available. Schlecter (1981) reviewed and supported the use of the Talent Unlimited Project as a guideline for teaching students techniques of forecasting and decision-making. Similarly, the Future problem-solving program is designed to bring into awareness one's relevant, domain-specific prior knowledge and experience to make outcome predictions (Hoomes, 1984). The Process-Oriented instructional design is another program that clearly supports the importance of forecasting and prediction-making as invaluable problem-solving processes (Baldwin, 1981).

These instructional methods provided valuable insight into the teaching of problem-solving, particularly in their concern about the use of prior knowledge in the problem-solving process. One commonality among these programs was that they all involved the use of brainstorming techniques as a means of bringing students' "stored" prior knowledge into awareness.

However, reliance on these programs should be tempered by two important considerations. First, evaluation of their effectiveness has not been rigorous, and there is no empirical evidence that observable, long term improvements result from their implementation. It is often true that outcome studies regarding program effectiveness are often difficult to execute and methodologically problematic. Baldwin (1981) evaluated the Process-Oriented Instructional Design, and reported that high-ability students showed high-levels of thinking when they had been exposed to the instructions; yet, the results of the study were not sufficient to conclude that implementing the program was effective, since the methodology did not compare the ability level of each student before and after the implementation of the program.

Second, these programs advocate the use of brain storming techniques to encourage students to search their minds for prior knowledge relevant to a given task. It is undoubtedly useful to learn how to access prior knowledge, but students are likely to need instruction in learning how to utilize prior knowledge in a goal-directed manner. Many of the available programs are not explicit in teaching the utilization of prior knowledge, and do not attempt to focus on teaching students the strategies needed to integrate prior knowledge with novel observations.

This study, therefore, responds to the need to directly teach the strategies for accessing and utilizing prior knowledge in problem-solving scenarios. Particular focus was placed on the prediction-making process of problem-solving, since the role that prior knowledge plays in prediction-making process is particularly important.

Science as a Specific Domain for Instruction

Bransford, Sherwood, Vye and Rieser (1986) commented on the importance of teaching problem-solving skills in specific domains. Research has found that general problem-solving skills may remain inert when the applications of these skills were not taught within a specific content area (Brown, Bransford, Ferrara, & Campione, 1983; Brown, Campione, & Day, 1981). These observations can be attributed to the limited ability human beings have to transfer knowledge and skills from one situation to another. The transfer of skill is not always automatic within a specific subject (Gunstone & White, 1980) and is particularly hindered across subjects (House, 1969). Simon (1980) thus advocated the teaching of problem-solving in specific subject areas for two reasons: (a) Subject-specific teaching of problem-solving facilitates the transfer of skills that were learned from another content area, and (b) such a teaching approach exposes the students to a whole continuum of problem-solving skills, from general to specific ones.

The selection of science as a content area, where the teaching of problem-solving can be of benefit, is in response to the philosophical and pragmatic significance of science education. Studies in the philosophy of science education testify that science is embedded in the total framework of human thinking and existence (Roberts, 1983; Robinson, 1968, pp. 126-127). Scientific theories guide the way in which human beings observe the world. Science advocates the qualities of being theoretical and exact, and regulates the ways in which observation are made, recorded and verified (Munby, 1982, p. 16). Thus, it becomes crucial that the goal of science education is set beyond the attainment of content knowledge. It should also include the understanding of how science guides our everyday lives and our intellectual development. Roberts (1983) outlined the intent of science education as understanding the structure and limitations of science, and the acquisition of scientific skills as a solid foundation for future learning (pp. 11-13).

The ability to adopt a scientific approach can greatly reduce the level of individual bias and provide the opportunity to make fully reasoned judgement about the common-sense view of the world (Conant, 1951, p. 130; Munby, 1982, p. 27). The ability to think critically is particularly important since society has evolved in such a way that science has become integrated into all parts of life. Existing thoughts are perpetually undergoing modifications through observations and hypotheses. Therefore, decisions have to be made constantly, and appreciation of the methods of science becomes invaluable.

From a pragmatic stance, science serves to provide an anchor in which problem-solving skills can be easily transferred and generalized to other situations in life (Bloom, 1956). Kyle (1980) suggested that the ability to scientifically inquire is the personal, internalized ability of an individual to synthesize the knowledge which has been obtained through learning experiences. This ability thus enables a person to rationally inquire and solve problems.

The scientific process includes inquiry skills such as observing, comparing, inferring, classifying and predicting (Holt, 1977). These are the basic processes for generating a solution in a problem-solving situation. When confronted with a novel situation, students need to carefully observe, compare, make inferences and predictions about the problem at hand, and the desired goal. They need to draw on past knowledge of similar or related phenomenon, and then make the conceptual link between the two (Copple, Sigel, & Saunders, 1984). Although the acquisition of these processes and skills are important, learners need to apply these skills in real inquiry situations to ensure true understanding of the applications of these processes (House, 1969; Renzulli, 1977).

The value of science education, then, is not merely to generate experience and knowledge in the subject matter, but to develop "tacit knowledge" where one can effectively interpret information or events and make judgements (Broudy, 1969; Klopfer, 1971). Prediction-making, decision-making and evaluation are all processes of science that are relevant to various situations regardless of subject or discipline (Aikenhead, 1980; Risi, 1982).

For the purpose of this study, the problem-solving process in focus is the accessing and utilization of prior knowledge for making predictions. This is particularly relevant in science education because it focuses on teaching students to make use of what they already know in attempting to predict consequences of events. The process of making a prediction that is rational and likely to lead to a solution can be derived from a series of causal-effect relationships (Friedman, 1984). The understanding of causal relationships is easily demonstrated in science, because most scientific phenomena are initially explained by observable, concrete, cause-effect relationships.

One of the ways of fostering prediction-making behaviors is by selecting appropriate science material and encouraging students to identify a sequence of observations that may lead to an outcome. In addition, students should be prompted to verbalize their understanding of relationships between events by imposing "why" questions. Through classroom discussions, students can then develop the process of accessing and utilizing their prior knowledge and experience (Copple, Sigel, & Saunders, 1984).

One of the processes of science which captures the utilization of prior knowledge in science lessons is found in the analytical scheme developed and applied by Wolfe (in press) in a class of high-ability students. The scheme is particularly relevant to this study because the characteristics identified with "rational ideas about science" can be applied to the process of problem-solving.

Wolfe suggests that in order to expose students to rational ideas, teachers should provide a framework for scientific investigations and problem-solving scenarios. The students should be taught to link their perceptions of what is known and understood about a given problem, with their prior knowledge of similar observations. Classroom discussions are necessary as they provide opportunities for the teacher to help the students relate prior knowledge and experience with the investigation that is taking place. In addition, students are encouraged to make sense out of new problems by drawing on information acquired from teachers, or other sources, and their own past experiences with similar events.

It is evident that the teaching of any problem-solving skill or process cannot be detached from specific content areas. Science is one of the areas in which problem-solving can be taught because of its wide implications in everyday life. Scientific problem-solving becomes a common and necessary process. Focusing on rational ideas about science can further emphasize the scientific processes to learners. These processes can then be applied to all problem-solving scenarios that are encountered.

CHAPTER 3

Methodology

Research Design

This study adopted a qualitative design for analyzing the way in which prior knowledge was used to make predictions in solving science problems.

Research studies have traditionally used quantitative designs in the comparisons between high-ability learners and average-ability learners (Foster, 1986). These studies typically employed large samples and the results did assure the statistical certainty of generalizing results to larger populations of high performing individuals. Research by Baldwin (1981) and Carter (1985) indicated the extent to which high-ability students excel, but failed to elaborate on the manner in which high-ability students' thinking processes were characteristically different from those of less able students. What is lacking in this type of research study is much of the unique and individual expressions of exceptional ability (Foster, 1986).

In studying problem-solving, combining quantitative research designs with qualitative investigations is preferred. Such a methodology would further demonstrate how the students execute problem-solving processes in order to arrive at a solution (Rogers, 1986). While it is important to know the statistical differences in scientific thinking ability of large populations of high and average-ability students, understanding how these differences are expressed demands equal concern (Bogdan & Miklen, 1982; Stake, 1978). The uniqueness of individual thinking processes is generally not evident in the reduced data of quantitative research. Understanding the thinking processes elicited by advanced learners may give valuable insights in understanding how they function differently. Such understanding further allows for the development of educational programs, curriculum implementation, teaching techniques, and other issues important in the development of enriched education for gifted, as well as for mixed-ability learners.

These methodological concerns support the decision to carry out the present study: to understand the nature and meaning of high-ability students' performance as they make predictions during problem-solving scenarios.

Quantitative data, then, will be included in this study as corroborative evidence. The qualitative data will identify the types of processes and levels of thinking when students of different ability levels make predictions. The quantitative data will permit frequency counts of the processes and behaviors exhibited and, thus, provide further evidence for the observed differences between high-ability and averge-ability students.

The following sections of this chapter describe in detail the method used to carry out the study. The sample chosen will be described, as well as the context in which the study took place. The two problem-solving scenarios which were presented to each of the students on two different occasions will be discussed. The final section will present the entire procedure for the investigation.

Context and Sample

The School

The study was conducted in a suburban public school in southern Ontario which operates on a "rotary" system. All students attend elective classes in the mornings and assemble for their "core" classes in the afternoon.

The Classes

During the "core" science class, 36 grade 8 mixed-ability students assembled under the supervision of Teacher A. Similarly, a group of high-ability students assembled under the supervision of Teacher B. The high-ability class included students from grades 6 to 8, with five students at the grade 8 level. The two teachers agreed to integrate the five high-ability students into Teacher A's mixed-ability class during the instructional part of this study. Thus in the newly reconstituted grade 8 class, there were 41 students in total.

The Teacher

Teacher A, of the mixed-ability class, was asked and agreed to participate in the study and deliver three science lessons to the reconstituted mixed-ability class. She has had experience teaching students of varied intellectual abilities, and had special training in science teaching. For the purpose of this study, she consented to adjust her teaching style during the three science lessons to focus on the accessing and utilization of prior knowledge in science investigations. No training was provided for the teacher, however, she was given a detailed description of an analytical scheme developed by Wolfe (in press). This scheme characterizes how and when prior knowledge could be accessed and utilized during science investigations. Prior to the science lessons, the experimenter discussed the characterizations of the scheme with Teacher A. The teacher then assured the experimenter that the specific instructions of how and when to utilize prior knowledge would be emphasized during the science lessons.

The Selected Sample

A sample of ten students was originally chosen from the newly reconstituted grade-8 class. However, a high-ability student was absent from one of the problem-solving scenarios and was thus excluded from the analysis. Among these nine students, there were five average-ability and four high-ability grade-8 students. The average-ability students were specifically selected from the mixed ability class by Teacher A based on the following criteria: (a) The students were of average standing in the class, and (b) they are verbally fluent, i.e., able to verbalize their thoughts without interfering with their thinking process. The four grade-8, high-ability students were confirmed by Teacher B as: (a) fulfilling the requirements of enrollment in a program for the academically gifted, that is, having full-scale IQ of 137 and above, and/or obtained a minimum stanine score of 9 in the Canadian Abilities Test, (b) recommended by a teacher and parents as having the potential to succeed in enrichment classes, and (c) exhibiting verbal fluency. Verbal fluency was considered a necessary criterion for selection because these selected students were asked to "think-aloud" and express all their thoughts while performing the task.

The students were individually assessed by the experimenter on two occasions. Extensive field notes of their classroom participation during science lessons were also collected by the experimenter.

Problem-Solving Scenarios

Two problem-solving scenarios were presented to the students, one before and one following the science lessons.

These problems were chosen from "Brain Booster" (Webster, 1965) and depicted the phenomenon of plant growth. The teachers who participated in the study confirmed that the problems were appropriate for grade 8 students in terms of the level of difficulty.

The first problem-solving scenario was presented on a piece of 21.5cm X 28cm paper (see Appendix A). The problem depicted a plant placed in a box with two openings where the light can enter. A short written description was also given to the students so that the amount of information available to them was standardized. The students were asked to make a prediction concerning the manner in which the plant may grow. This question required that students know and understand that plants have the tendency to bend towards a light source.

The second problem-solving scenario was also presented to students on a piece of 21.5cm X 28cm paper (see Appendix B). The problem depicted a potted plant with a plastic bag tightly tied around the pot and the lower part of the stem, with all the leaves exposed. A short written description relayed appropriate information to all the students. They were required to predict whether the entire plant (including the pot, the soil, the plastic bag and the plant itself) would weigh more or less after a duration of a few weeks. In order to address this question, students needed to have a clear understanding of the concept of transpiration.

These two problems were similar in that they required students to make a prediction about the outcome. However, there was no definite solution to the problem, since the nature of the predictions would be contingent upon the assumptions that the students adopted. The experimenter was primarily concerned with how students make the prediction, and with particular focus on how each student's prior knowledge about plant growth was utilized in the process of prediction-making.

Procedure

The study took place over a period of 8 days. The first day was allocated for general observation and familiarization of the students who constituted the sample of the study.

On the second and third day, the four high-ability students and five average-ability students were individually interviewed by the experimenter. They were presented with the first problem-solving scenario. After a student completed the problem-solving scenario, an interview was conducted by the experimenter in order to gain an understanding of each student's sources of science knowledge.

The fourth, fifth and sixth days were set aside for the science lessons. These consisted of three 40-minute lessons prepared and delivered by Teacher A. The content of these lessons was different from that of the problem-solving scenarios.

The seventh and eighth days were allocated for the second problem-solving scenario in which the four high-ability students and five average-ability students were assessed individually. After each of the students responded to the problem-solving scenario, another interview was conducted by the experimenter. The objective of this interview was to determine whether the student understood the importance of accessing and utilizing prior knowledge during problem-solving scenarios.

Familiarization Procedures

On the first day of the study, the five high-ability students were integrated into the mixed-ability grade 8 class during the last lesson of the day. Teacher A introduced the experimenter, and explained that five grade 8 students from Teacher B's class would be joining them for three lessons during the following week. The experimenter then explained to the students that she was interested in seeing how teacher and students interact during science lessons. The students were asked to behave as they normally do in their classroom, and to pretend that the experimenter was not present. The experimenter also explained that ten students had been randomly selected from the class to meet with the experimenter individually. Those students were, in fact, selected with respect to pre-set criteria as described in the sample. The purpose of this deception was to ensure that students would not question the reason for their selection or nonselection.

The experimenter then took the ten selected students to the school library where she, again, introduced herself and became familiar with the names of the students. She informed the students that she would be seeing each of them individually on two occasions in order to find out how they approach a science problem. In order to understand their approach to a science problem, they would be presented with one problem-solving scenario during each of the two occasions. The students were assured that the problems had no right or wrong answer, and that they would not be graded on the accuracy of their response. The experimenter emphasized that she was interested in what students think about when they approach science investigations, and where the knowledge comes from.

Subsequently, the experimenter presented the students with a hypothetical situation in which they were asked to predict what would happen. The purpose of this preliminary procedure was to prepare the students for the "think aloud" procedures of the problem-solving scenarios with the experimenter.

First Problem-Solving Scenario

The first problem-solving scenario was given to the students during two afternoon sessions before the science lessons. The investigation took place in a small room that was normally used as a guidance centre. The teacher determined the order in which the students met with the experimenter. The schedule was established in such a way that least disrupted the students' normal classroom activities. One high-ability student was absent from this procedure and he was excluded from the subsequent experimental procedures. Therefore, in all subsequent procedures, there were only nine selected students.

Each student entered the room and was asked to close the door to ensure that no disruptions would interfere with the procedures. The student was then asked to sit beside the experimenter. They engaged in a short casual conversation (about 2 to 3 minutes) to make the student feel more relaxed. The experimenter explained that a tape recorder would be used to record the procedure because she would not be able to write down all the details quickly enough. The experimenter then presented the problem-solving scenario (see Appendix A) and asked the student to look at the problem carefully. The student was then asked to describe what would likely occur. The experimenter reminded the student to verbalize everything that came to mind, and to further explain how the prediction was made. This procedure is called "think aloud," which all the students had practice doing during the familiarization meeting with the experimenter.

When each student was giving the verbal report, the experimenter periodically addressed the student with "Can you think of any thing else?" to ensure that the student had reported everything in mind. Occasionally, a student would require cueing when there was no response. The experimenter used cueing statments such as: "What made you think of that?", "How did you know that?", or "Did you learn that from school or somewhere else?".

When the initial verbal response was collected, the experimenter told the student that she would like to have more detail, and that she would replay the tape and pause at intervals in order to ask for clarification. The experimenter was primarily interested in finding out where each of the students got the information for their particular predictions. Again, this question-answer protocol was audiotaped. Each of the nine students was assessed in the same manner and they were each given the same problem-solving scenario to consider.

<u>Interview 1</u>

Following the presentation of the first problem-solving scenario, the experimenter asked each student questions about the source of their prior knowledge. The questions included the types of magazines and books that the student was interested in, the types of television programs watched, and whether there were other significant persons that provided scientific knowledge. This procedure was also audiotaped. When the entire interview was completed, the student was thanked and dismissed. Each of the nine students was interviewed in the same manner.

Science Lessons

During the science lessons, Teacher A was required to teach the students how to access and utilize their prior knowledge in science investigations. The teacher chose to implement these teaching objectives in three lessons devoted to the topic of electromagnetism. The implementation of this treatment was in response to one of the purposes of this study, that is, to look at the ways in which direct teaching of accessing and utilization of prior knowledge can be effectively used in problem-solving. In addition, the ways in which students of high-ability and average-ability differ in their response to the treatment was investigated.

These lessons took place during the last class period on each of three days. All the students of the reconstituted mixed-ability class attended these science lessons. They randomly sat around six tables, with the nine selected students seated randomly at different locations in the classroom.

During the first lesson, Teacher A introduced her three-lesson plan. She informed the students that in each of those lessons, there would be investigations of magnetism, and that their written classwork would be evaluated. During the three lessons, the experimenter observed the interactions and noted the participatory behavior of the nine selected students in terms of attentiveness, class discussions, enthusiasm in investigations, and discussion within their groups. The lessons were also audiotaped using two audio cassette recorders strategically placed in the classroom. When the students proceeded with their investigations, the experimenter circulated in the classroom to observe the progress of each group. The experimenter acted as the teacher's helper only during the third lesson, when she went to each group of students and sprinkled iron filings on sheets of paper placed over a magnet.

Second Problem-Solving Scenario

The second problem-solving scenario (Appendix B) was used when the experimenter met with each of the students after the science lessons. The method of collecting the verbal protocols was identical to that used during the first problem-solving scenario.

Interview 2

After the students responded to the second problem-solving scenario, the experimenter conducted another interview with each of the students. The goal of these interviews was to inquire about the extent to which students understood the significance of using prior knowledge in problem-solving. In addition, the students were asked to verbalize their understanding of how prior knowledge could be accessed and utilized in their science learning.

CHAPTER 4

Description and Coding of Data

This chapter will be devoted to a description of how the data, collected from various sources, was organized and coded.

The three science lessons were recorded and then transcribed. The information from these lessons was used to (a) determine how the students were taught to access and utilize their prior knowledge in a problem-solving scenario, and (b) confirm that students were expected to use these skills in making predicitons.

The students' verbal protocols, gathered during the problem-solving scenarios before and after the science lessons, were recorded and transcribed. The data were analyzed by identifying predictive statements and were coded according to Taylor's (1968) criterion. The verbal protocols were also analyzed and coded according to Langer's scheme (1981) and Bloom's taxonomy (1956). Explanation of these criteria and justification for their use are presented later in this chapter.

The two interviews conducted with each student after each of the problem-solving scenarios were recorded and transcribed. The information from the first interview was used to explain the difference between high-ability and average-ability students in terms of their prior knowledge integration. The information of the second interview was used to corroborate the observations of students' behavior during the problem-solving scenarios and science lessons.

Miscellaneous data, which included a description of fieldnotes and students' work projects during the science classes, were examined in order to substantiate the claims made concerning the activities during the science lessons. These notes focused on students' behavior during the science lessons, and provided evidence to reflect whether the science lessons conveyed the anticipated teachings about prior knowledge.

Data from the Science Lessons

In order to investigate the effects of teaching students to access and use their prior knowledge, three science lessons were implemented and observed. The teacher-student interactions were transcribed and information was extracted concerning the manner in which the teacher carried out the planned objectives. These transcriptions were analyzed to ensure that the treatment goal was accurately addressed. Throughout this study, excerpts from the science lessons are presented, in parentheses, in the following format:

(S,1,9)

This representation refers to the science lesson (S), the first lesson (1), and the 9th statement selected from the protocol (9).

Data from the Problem-Solving Scenarios

The verbal protocols were gathered from the problem-solving scenarios before and after the science lessons. Two sets of protocols were generated. The first set consisted of the student's initial think-aloud responses, and the second set consisted of the initial think-aloud, intertwined with question-and-answer discussions between the experimenter and the student. For the purpose of this study, the second set of protocols is used as the final data for analyses since it includes all the verbal information recorded during each problem-solving scenario.

The verbal protocol was organized in columns to facilitate analyses. In order to make a distinction between the initial think-aloud and the subsequent question-and-answer discussion between the experimenter and the student, the initial think-aloud of each student is presented in bold print. The question-and-answer discussion between the experimenter and the student is presented in regular print. (The complete set of protocols and analyses for each subject is not included in this thesis, but is available for examination upon request. Sample protocols of one high-ability and one average-ability student are presented in Appendix C).

Since this study is directed at students' prediction-making behavior during problem-solving scenarios, only the relevant information was extracted and is presented as the "summary of verbal protocols" (Appendix D).

Justification for Data Coding Schemes

Prediction statements were selected based on Taylor's (1968) notion of forecasting. Forecasting is defined as the ability to foresee patterns, chains of events, or cause and effect relationships. By keeping an open mind and exploring all of the possible conditions that may affect the results, a prediction can be derived (cited in Maker, 1982). Taylor's (1968) notion of "forecasting" is relevant to the objective of this study. A prediction statement can be identified as a possible outcome that is neither given, nor readily apparent, in the problem.

In addition, students also explained how they arrived at their prediction and these explanation statements were also extracted from the protocols. These explanation statements were analyzed to reveal the level of integration of students' prior knowledge using Langer's (1981) method of coding.

Langer (1981) provides a method of analyzing verbal data in order to understand the organization and integration of prior knowledge. The coding scheme was originally developed for analysis of text comprehension. Construction and application of the scheme was based on the assumption that the organization and categorization of prior knowledge is directly related to the retrieval and utilization of the knowledge from various sources. The coding scheme provides an analysis of the level of integration and organization of prior knowledge statements. (a) Much association refers to superordinate conceptions of prior knowledge, demonstrating evidence of high-level integration of knowledge by giving definitions, analogies, or a linking of that concept with another concept. (b) Some association refers to concepts with some integration of prior knowledge, generally taking the form of attributes, examples, defining characteristics. (c) Little association includes morphemic associations, sound-alikes, or firsthand experience rather than concrete understanding.

Langer's categories were developed under the assumption that all knowledge is structured in terms of a "propositional network" (Anderson, 1976; Anderson & Bower, 1973). This network is made up of a set of information and knowledge linked together to form complex relationships. Thus, the more complex the linkages, the more integrated the prior knowledge. These complex links also facilitate the retrieval of information and knowledge that is crucial for new learning, problem-solving, and other intellectual tasks. Langer (1982) applied the phenomenon of knowledge integration to text comprehension and confirmed that good readers are aware of the structure of their prior knowledge and make full use of it.

The notion of knowledge integration is particularly relevant to science investigations. Science and reading are similar learning situations that rely on the reader's past experience and knowledge (Langer, 1982, pp. 151-153). The processes, such as predicting, planning, checking, evaluating, comparing and monitoring are important processes executed during reading activities. More importantly, these are also unavoidable processes of science. Therefore, there is some justification in adjusting the Langer coding scheme to the categorization of science knowledge.

The explanation statements selected from the students' protocols were also analyzed according to the way in which the level of thinking was inferred. Bloom's taxonomy (1956) provided six categories of cognitive behaviors: knowledge, comprehension, application, analysis, synthesis and evaluation. These six categories are presented in an order that depicts progressively complex thinking behaviors, i.e., accurate display of a higher-level thinking is less probable than a relatively lower-level thinking (Bloom, 1956, p. 19). The application of these categories permitted inferences to be made concerning how students manipulated their prior knowledge in various cognitive activities.

Combining the categories of both Langer (1981) and Bloom (1956) facilitated analyses of the data for this study. The two schemes provided evidence about the correspondence between complexly organized knowledge (from Langer) and the ability to use the knowledge to induce high-level thinking (from Bloom).

Summary of Verbal Protocol

Predictive statements, explanation statements, coding of prior knowledge integration and level of thinking, together comprised the "summary of verbal protocol" (Appendix D). Each of the prediction and explanation statements was assigned a "statement number" for reference purposes.

In the "summary of verbal protocol," information is presented in four columns: (a) predictive statements, (b) explanation statements, (c) coding of explanation statements as they infer cognitive behavior outlined in Bloom's Taxonomy (1956), and (d) coding of explanation statements according to the adjusted Langer's (1981) scheme. Throughout this thesis, references to the "summary of verbal protocol" are made, in parentheses, in the following manner, For example:

(HA2,A,23)

refers to the second high-ability student (HA2), who responded during during the first problem-solving scenario (A), and the 23rd statement that the student made. Similarly, (AA5,B,15) refers to the fifth average-ability student, who responded in the second problem-solving scenario, and the 15th statement made by that student.

The selection of the predictive statements and the two coding schemes for the explanation statements are outlined, in detail, as follows:

<u>Coding predictive statements</u>. Predictive statements were identified using Taylor's (1968) criterion. Examples of such statements are as follows:

(1) I think that the plant would die.

(2) It will grow towards the larger one.

(3) It is going to weigh considerably less.

<u>Coding levels of integration</u>. Langer's (1981) scheme was adjusted to be used in categorizing prior knowledge of science according to three levels of knowledge integration. Integration of knowledge, in the context of science, refers to the relationship between concepts, ideas and information. Thus, a high degree of integration would correspond to complex relationship within knowledge structure. The adjusted coding scheme is as follows, with examples from the students' protocols:

(a) Well-integrated statements would involve giving definitions of scientific terms, linking of concepts, and making analogies between related science events, for example,

(1) condensation causes humidity;

(2) in a closed system, you have the water cycle;

(3) a plant would die if it doesn't have light.

(b) Moderately integrated statements would convey attributional properties of scientific phenomenon, define characteristics, or present a parallel example, for instance,

(1) with the plastic bag, water evaporates;

(2) the leaves have veins to draw the fluid;

(3) water will evaporate from the pores.

(c) Statements which lack integration are those that report vague associations between events, first hand experiences and/or direct observations, etc., for example,

(1) the roots in the water soaks up the water;

(2) I saw this in the plants at home;

(3) water is not just going to stay in the bottom.

All the explanation statements obtained from the students' protocols were, in this way, categorized by one of the above categories. The codings reflected the degree of integration that was evident in students' p ior knowledge concerning plant growth.

Coding levels of cognitive behaviors. Bloom's taxonomy (1956) was applied in classifying explanation statements into one of the six levels of cognitive behaviors. The coding scheme is as follows, with examples taken from the students' protocols:

(a) Knowledge: Information that one remembers, either by recognition or recall, for example,

(1) plants need water for normal growth;

(2) water evaporates from the surface of the leaves;

(3) chlorophyl makes the leaves green.

(b) Comprehension: Grasp of meaning or intent of oral or written material, for example,

(1) the plant is going to use the water from the soil;

(2) the plant is in a box and the light comes through here;

(3) more light is coming in through the bigger hole.

(c) Application: Remembering and applying generalizations and principles to given material, for example,

(1) the roots are going to use it up for plants normal growth;

(2) the soil will soak the water up;

(3) it will evaporate, like, if you spill water, it'll dry up.

(d) Analysis: A breakdown of information into constituent parts in order to detect interrelationships, for example,

(1) when it is small, it is going to turn to the bigger hole because more light gets in;

(2) the plant is going to try and get sunlight and minerals, cause it needs it;

(3) if it is in this stage, it would grow towards the top.

(e) Synthesis: Putting parts together to form a whole, for example,

(1) with light, it is green, without light it is brown; this shows that sunlight is necessary;

(2) the plant has grown bigger because it has found sunlight.

(f) Evaluation: Making judgement, for example,

(1) the plant has to grow, it is going to keep growing this way;

(2) the weight will be less because all the water will be evaporated;

(3) it will lose some weight, but not too much, since part of it is protected.

Students' explanation statements were coded according to the above six categories. The codings reflected those cognitive behaviors exhibited by students as they make predictions.

Data From Two Interviews and Miscellaneous Data

Interviews

The interviews were audiotaped and transcribed. Analysis revealed that the students obtained their science knowledge from teachers, siblings, parents, television, magazines and books. Extracts of students' sources of knowledge are presented in Appendix E. Information from the interviews was then used to corroborate the results concerning each student's level of knowledge integration and their display of cognitive behaviours.

During the second interview, students were asked (a) whether they perceived that prior knowledge was important for learning situations, and (b) how they would use their prior knowledge in science investigations. The protocols from these interviews are presented in Appendix F. The purpose of the science lessons was to alert students to the importance of accessing and utilizing prior knowledge, and to teach them specific skills in accessing and utilizing this knowledge. The students' responses in the second interview would, therefore, give insight concerning how well these understandings and skills were conveyed during the science lessons.

Selected excerpts from the interviews are presented in the following manner, for example,

(I2,HA3)

represents the second interview (I2) and a statement made by the third high-ability student (HA3). Similarly, (I2,AA5) refers to the second interview and a statement made by the fifth average-ability student.

Miscellaneous Data

This study includes fieldnotes of students' classroom interactions during the three science lessons. Students' participation and on-task behavior were noted, and would provide additional understanding concerning the students' reactions during the science lessons. Reports of students' projects, carried out during the lessons, were also recorded and reviewed. The ways in which the students had used their prior knowledge during the classroom investigations could be evident in these in-class project sheets. These miscellaneous data were also referred to in the analyses of the science lessons.

CHAPTER 5

Results

The previous chapter described the manner in which the data were organized and coded. This chapter presents the analyses of results of this study. The science lessons are examined and reveal that the specific objectives of the lessons were only partially fulfilled. Analyses of the students' protocols during the two problem-solving scenarios are subsequently presented. The application of Langer's (1981) scheme revealed that high-ability and average-ability students showed different levels of integration of prior knowledge. Students' ability to engage in higher-level thinking was compared using Bloom's taxonomy (1956) as an analytical scheme. Finally, the relationship between Bloom's and Langer's codings is analyzed and discussed.

Analysis of the Science Lessons

Three science lessons on "electromagnetism" were scheduled during the last period of three consecutive days. It was intended that the teacher would incorporate "Rational Ideas About Science" (Wolfe, in press) in her teaching process by providing direct instruction on how to access and utilize prior knowledge during the science investigations. Transcripts of these lessons are available upon request.

Analyses of the lessons showed that the planned objectives were only partially fulfilled. The teacher did present the importance of accessing and drawing on prior knowledge. However, she did not put emphasis on teaching the students how to utilize their own prior knowledge in particular or novel situations. Interviews with the students, carried out following the science lessons, confirmed that the students were aware that using prior knowledge was important for new learning. They were not, however, proficient in using their knowledge in novel situations.

Extracts from the science lessons that capture the emphases on accessing prior knowledge are presented in the following section. Supporting evidence from students' in-class projects is also included to substantiate the evidence.

Accessing prior knowledge. Transcripts of the lessons provided evidence that the teacher did convey to students that it was necessary to gain access to one's prior knowledge in learning situations. The following extracts are taken from the first lesson (the notation following each statement is explained in Chapter 4):

T: We are finding that the more things that you can bring out of the back of your heads, the better you can learn in science (S,1,2). For each of these lessons, it is very important that you try to bring out as much as you possibly can. Bring them out from the back of your heads (S,1,3).

The teacher then encouraged the use of "brainstorming" techniques to lead students through the process of bringing into awaremness what they already knew about electromagnetism. For example:

T: Here is the way the lessons are going to go. I'm going to start off today doing brainstorming (S,1, 4).
What you do this afternoon will depend on how much you can successfully bring out from your head. So you really have to think about <u>everything</u> that you know about electromagnetism (S,1,5).
The rule of brainstorming is that you cannot exclude any ideas (S,1,6).
Remember what I have just said: how you are going to do well in the investigation that we will do later, depends on how much about magnetism you get out from your head.

Throughout the science lessons, the importance of accessing all the prior knowledge on magnetism was drawn to the attention of students. For example:

> T: Let's say this is how much you've got in your head and this is how much you've been able to pull out (draws a cube on the board and indicates that it is half full). Using what we've just brought out and hearing what someone else just said, think of anything else that you can put down (S,1,11).

Supporting evidence was further generated from careful observations of students' in-class projects. Both ability groups responded well to the teacher's encouragement to access prior knowledge and students were able to generate long lists of information related to electromagnetism. (Students' in-class projects can be provided upon request.) Close examination of these lists suggested that students abided by the rule of brainstorming, i.e., not to preclude any ideas, and to include a range of relevant information from specific to general statements.

The above observations thus suggested that the three science lessons were successful in teaching students how to <u>access</u> their prior knowledge. In the following section, the other objective of the science lessons, i.e., to teach students how to _utilize_ their prior knowledge, is discussed. Interviews with the students after the lessons were used to corroborate the results obtained from protocols of the science lessons.

Utilizing prior knowledge. It was intended that the teacher would lead the students through investigations and discussions and explicitly teach them how to make use of their prior knowledge in science investigations. Analyses of the lessons indicate, however, that the students were grouped together and asked to carry out their investigations and discussions within the groups. For example:

> T: I'm going to put you in groups of three. I want you to come and get a set of magnets, a compass, and some paper clips (S,1,12).
> Then, I want you to go back to where your brainstorming sheet is (S,1,12).
> I want you to pick one thing that you will investigate with the other two people in your group, using magnets, a compass and paper clips (S,1,15).

> T: O.K. I want you to stop right now. Put everything you have in your hands down and look over here. I want you to write down everything you did by

> answering the work sheet for Investigation One. Write down what you investigated and how you went about doing it. Write down also what you saw and how you could explain what you saw. You can discuss it with your two group partners. You have ten minutes to do this, and then you'll clean up and bring out all the magnets, compasses and paper clips (S,1,16).

The teacher did not lead the students through any discussion, nor did she provide the students with explicit instructions or examples on how to utilize their prior knowledge in novel investigations. The students were provided with little guidance throughout the investigations. Although the teacher did circulate from group to group to observe the students' investigations, they were left to freely explore their own ideas.

Evidence to suggest that students were not proficient in utilizing their prior knowledge was also found in the interviews. In the second interview, after the science lessons and following the second problem-solving scenario, students were asked to respond to two issues: (a) whether they believe that, in science, it is important to make use of what is already known, and (b) how prior knowledge can be used in new investigations (Appendix F).

Review of the students' responses during the interview suggested that all the students were aware that prior knowledge plays an important role in learning situations. They all responded to the first question in the affirmative. Some of the students gave further elaborations that making use of prior knowlege helps to "remember more" (I2,AA2), and is important for making "guesses" in novel situations (I2,HA1).

When asked to explain <u>how</u> prior knowledge could be used in science investigations, none of the students was able to explain how prior knowledge can be used. Some of the students stressed that prior knowledge enables the learner to understand classroom lessons better. For example:

AA1:Well, if we use what we already know and put it with stuff that we're learning now, we might understand it better (I2,AA1).

AA2:Because if you know something, that might bring more things to your mind about things that you are learning about (I2,AA2).

HA3:If you do know [something], then it's really nice because then you have it right there and you know what they're talking about and it's really easy to understand what they're talking about (I2,HA3,2).

Responses of some students indicated that they believed that prior knowledge can be helpful by providing an anchor for new learning. For example:

HA2:If you already know a little something, then you can look up more things to get more detail (I2,HA2).

You already have a background in which to work at (I2,HA2).

If it was something that was buried deep in your understanding, you already know something about it, it would help you research it (I2,HA2).

HA3:I think it is because we get more knowledge as we go along and out past experience and knowledge can also help us when we're learning new stuff (I2,HA3).

Students' responses during these interviews suggested that they were taught that prior knowledge is important in investigations, but they lacked the understanding of how prior knowledge could be utilized in the investigations. These observations corroborated with the evidence that the science lessons, indeed, alerted students to retrieve and access prior knowledge through brainstorming techniques. In spite of this, the students were not provided with explicit instructions and guidance on how to apply the prior knowledge to their investigations.

Since the objectives of the science lessons were only partially fulfilled, students' ability to utilize prior knowledge in problem-solving scenarios, before and after the science lessons, will not be compared. This decision is also supported by the evidence that students' problem-solving behaviours before and after the science lessons was not significantly different. Thus, in the following section, discussions of the students' knowledge integration and levels of thinking consider their behaviours in both problem-solving scenarios.

Analysis of Students' Protocols

Level of integration of prior knowledge. In order to look at the way in which students integrated their prior knowledge, Langer's coding scheme was adjusted to provide three categories in which students' prior knowledge was considered to be well integrated, moderately integrated, or lacking integration. The experimenter and two blind-raters classified students statements of prior knowledge, and reached an inter-rater aggreement of 96.44%.

A close look at the students' responses supports the view that the high-ability students who participated in this study presented well-integrated statements of prior knowledge across the first and second problem-solving scenarios. For instance, in making predictions about the weight of the plant (Appendix D), the high-ability students reported that the weight of the plant would be considerably reduced. One student explained it this way:

> HA3: The water in the pot is going to the leaves (HA3,B,2),
> the plant is going to use the water in the soil (HA3,B,3), and
> water evaporates from the surface of the leaves (HA3,B,14).

This series of responses infer that prior knowledge was well understood and well integrated. The student showed an understanding of transpiration and, in turn, an understanding of the relationship between the given conditions of the problem and the natural processes of plant development. Further examples of well integrated statements made by high-ability students are presented below:

> "it is natural for a plant [to die] if it doesn't have qualities like water, sunlight (HA4, A,11)"

"most plants need light to survive (HA1,A,5)"

"the water goes to the leaves and it's probably evaporated from the sun (HA4,B,10)"

"the plant is going to use water from the soil (HA3, B,3)"

"when it is hot, [water] will evaporate inside the bag (HA3,B,7). When it eventually cools down, it'll go back into the pot again. In that way, the plant will use [the water] and then whatever is not used will evaporate onto the bag, and so on (HA3,B,8)"

The following examples of explanation statements made by average-ability students demonstrated lack of integration of prior knowledge:

"[moisture] comes from the soil when you water the plant (AA1,B,6)"

"[the roots] live in the soil, the soil doesn't have the light (AA1,A,6)"

"if plants don't get moisture, they will all dry up (AA2,A,15)" "[the water] would come out at the bottom, you'd have a muddy batch (AA3,B,53)"

"[water] will soak into the stem. [The stem] is like a sponge or something (AA4,B,11)"

"[without the moisture] the soil will become hard like a rock and the roots won't be able to travel. It'd be too hard for [the roots] to push through (AA5,B,7)"

These statements illustrated that the average-ability students, in this study, showed a lack of integration of their prior knowledge in the first and second problem-solving scenarios. Their statements typically conveyed poor use of scientific vocabulary. These students adopted concepts without clear understanding (AA3,B,53; AA4,B,11; AA5,B,7), and their knowledge and information were generated from daily observations.

Other supporting information, concerning students' sources of prior knowledge, was obtained from the first interview with the students. Students' sources of information or prior knowledge contribute, in some way, to the level of integration of their prior knowledge. It is likely that information and knowledge generated from varied sources would give the students multi-dimensional confirmation on a particular phenomenon. Consequently, the students view the phenomenon in light of its relationship with various other events. This process of acquiring knowledge is likely to generate a well-integrated body of knowledge. In order to gain insight into the relationship between sources of knowledge and organization of knowledge, interviews with the 9 students were conducted and analyzed concerning their global learning environment, i.e., family, teachers, the books that they read, and the television shows that they watch (see Appendix E).

Close examination of the interviews suggested that high-ability students, indeed, had a wider network of information and knowledge when compared with the average-ability students.

Three out of the four high-ability students indicated that their usual science teachers encourage them to consult reference books available in the school library. In contrast, only one out of the five average-ability students recalled that their usual science teacher had suggested that they use the library for additional information. The other four average-ability students perceived their science teacher as "just [giving] the lessons in the class" (AA1, Appendix E).

Additionally, three out of the four high-ability students viewed their parents as encouraging in their learning, and only one of the five average-ability students gave indication that parents' encouragement was prevalent.

Learning could be self-initiated by the learner as well, and could be evident in students' reading habits and their television viewing. The high-ability students all reported that they did extra reading when they had to do a science project, and they sought science information from science television programmes such as "Owl." Average-ability students, on the contrary, reported that they either rarely read books, or only read in subject areas that they particularly favored, none of which was centered around science. They all indicated that reading science magazines was an exception to the rule, and viewing science television programmes was not their preference.

This information about the differences between high-ability and average-ability students in their learning habits and learning environment upheld the evidence that the former had gathered their information from a wider variety of sources. In turn, they were in a more advantaged position to view the information that they gathered in various perspective, and to further gain insight into how science knowledge can be interrelated and integrated. Thus, the students' learning environment provided support for the observation that high-ability students, in our study, had well integrated prior knowledge related to plant growth and development.

Overall analyses of the first and second problem-solving scenarios also suggest that the high-ability students not only were able to report statements that are well integrated, i.e., drawn from multiple sources, they also reported a higher percentage of such statements when compared with the average-ability students. In order to capture this difference between the students of the two ability groups, a simple count was taken of the number of well-integrated statements, and those statements which lacked integration. The statements were then weighed against the total number of statements that a student had made, and expressed as a percentage of total statements.

For instance, student HA2 made a total of 17 statements during the problem-solving scenario, before the science lessons, and 7 of these statements were well-integrated. This corresponded to 41.1% of well-integrated statements. In contrast, 2 of the 17 statements that showed a lack of integration, resulted in 11.8% of the total statements that lacked integration. In the second problem-solving scenario, after the science lessons, 46.2% of the statements made by this same student were well integrated (6 out of 13 statements), and 7.6% of the statements lacked integration (1 out of 13 statements).

For each student, an overall percentage of well-integrated statements and those which lacked integration, was calculated by considering student's responses in the two problem-solving scenarios. For instance, student HA2, cited above, reported an overall 43.7% of well integrated statements (an average of 41,1% and 46.2%), and 9.7% of statements that lacked integration (an average of 7.6% and 11.8%).

Finally, the high-ability and average-ability students were separated into two respective ability groups, and an averaged percentage of well-integrated statements and those which lacked integration were tabulated for each of the two ability groups.

This analysis revealed that high-ability students in the study reported more statements of prior knowledge that were well integrated. Although these students also had presented knowledge statements that lacked integration, overall, the proportion of well integrated statements appeared to be higher than those that lacked integration (38.4% vs. 17 5%, respectively). Conversely, the trend was reversed among average-ability students. These students communicated a high proportion of prior knowledge statements that lacked integration, and in only a scattering of instances did they demonstrate some ability to deliver prior knowledge statements that were well integrated (63.3% vs. 3.9%). Chi Square Test of Homogeneity revealed that the differences between high-ability and average-ability students reached statistical significance ($\chi^2(2, N = 9) = 243.0$, $p < .001$). These results are shown in Table 1.

Table 1

High-ability versus average-ability students:
A comparison between the proportion of well-integrated and lack of integration statements.

	high ability	average ability
high level integration	38.65%	3.86%
lack of integration	17.53%	63.33%

In summary, the high-ability students in this sample demonstrated that their prior knowledge was better integrated when compared with the average-ability students. In contrast, the average-ability students were more likely to have knowledge that was generated from first hand experiences and lacked integration.

Levels of thinking. Understanding of students' level of thinking is facilitated by the use of Bloom's Taxonomy (1956). It includes six levels of thinking with progressive complexity: knowledge, comprehension, application, analysis, synthesis and evaluation. Data analysis for this study was guided by this taxonomy in order to understand the level of thinking displayed by the high-ability and average-ability students who participated in the study. The experimenter and two blind-raters determined the level of thinking, and reached an inter-rater agreement of 95.56%.

Overall analysis of the students' protocols in the two problem-solving scenarios revealed that the high-ability students who participated in the study were more capable of using their prior knowledge to produce higher-level thinking. In contrast, the average-ability students characteristically demonstrated lower-level thinking more readily.

The average-ability students in the sample typically reported straight-forward reiteration of prior knowledge and observations. This type of knowledge statement represented low level cognitive behaviors that reflected little understanding. For example:

> "[plants] grow when sunlight is coming all around it (AA1,A,4)"

"the pots are made of cement stone....some of them have holes at the bottom (AA3,B,52)"

Some of the statements made by the average-ability students demonstrated the lowest level of understanding. They were able to make use of materials and information and restate them in their own words. Yet, they were unable to relate the information with other ideas or knowledge, nor were they able to predict common trends and generalize their understanding to more complex situations. This type of thinking process was reflected in the ability to demonstrate comprehension of their prior knowledge, for example:

"[the water] would come out of the bottom....you'd have a muddy batch (AA3,B,53)"

"if you take the bag off, [the moisture] would just go straight up [along the stem] (AA3,B,10)"

Students of both ability groups were able to apply prior knowledge to other situations in which similarities were apparent and easily observed. They demonstrated the ability to make applications. For example:

"the stem is like a sponge or something (AA4,B,11)" "with the light coming in....leaves would start coming out (AA3,A,15)"

"the roots are going to use [the water] up for the plant's normal growth (HA3,B,4)"

The ability to analyze suggested the ability to detect relationships between events and observations, and was more evident among the high-ability students in the sample. They reported statements such as:

"[the plant] needs water to grow, but if there is too much water....it would have to get rid of it (HA2,B,19)"

"[the larger light source] will give [the plant] more chance for getting the minerals it needs (HA3,B,18)"

The high-ability students in the sample were also likely to exhibit synthesis. Not only were they able to detect relationships in their observations, they were also able to make sense or the relationships to produce a unified concept. This was captured in such statements as:

"the plastic bag is insulating, makes it hotter inside. [The water] will evaporate, and then it would turn from water vapor to water condensing on the sides of the bag (HA4,B,16)"

"when it eventually cools down, [the water] will go back into the pot again. In that way, the plant will use it and then whatever is not used will evaporate onto the bag and so on. The cycle will be repeated (HA3,B,8)"

Evaluation was observed only among high-ability students, although with low frequency. This level of thinking was evident when a student attempted to assess the validity of an observation or an argument, for example:

"[the plant] has to grow....it has to keep growing this way (HA3,A,38)"

"if there is no bag around it, then most of the water even before it gets up to the plant is going to evaporate (HA3,B,15)"

One objective of this study was to examine the difference between high-ability and average-ability students in their levels of cognitive behaviors. Further evidence was also found to support the claim that higher-level thinking was characteristic of the high-ability learners in the study. A simple count compared the percentage of statements at each level of thinking.

An overview of the comparison between the students of the two ability groups suggested that average-ability students frequently reported statements that indicated lower-level thinking, such as "knowledge" and "comprehension," when compared with their high-ability counterparts. Contrarily, high-ability students were able to demonstrate higher-level thinking, such as "application," "analysis," "synthesis," and "evaluation," more often than the average-ability students. A comparison, across the two ability levels, in each level of thinking was obtained. Chi Square Test of Homogeneity revealed that the differences between the two groups of students reached statistical significance ($\chi^2(5, N = 9) = 187.05, p < .001$). These results are illustrated in Table 2.

Table 2

Percentage of statements for each cognitive behaviour as a comparison between high-ability and average-ability students.

	high-ability students	average-ability students
Knowledge	24.6%	35.8%
Comprehension	18.7%	55.8%
Application	13.5%	12.5%
Analysis	14.9%	5.4%
Synthesis	22.9%	1.4%
Evaluation	14.8%	0.0%

In summary, it was observed in this study that the high-ability students made more attempts at higher-level thinking than their average-ability counterparts. In addition, the average-ability students more frequently exhibited tendencies towards lower-level thinking.

Utilizing prior knowledge in science investigations. This study investigated the difference between high-ability and average-ability students in their ability to use their prior knowledge in manners that facilitate the display of high-level thinking. It should be emphasized that although well-integrated prior knowledge (as assessed by Langer, 1981) can produce higher-level thinking (as labeled by Bloom's cognitive taxonomy, 1956), this relationship is not necessarily a direct one. Higher-level thinking can be observed only when prior knowledge is effectively utilized.

Close examination of the protocols of the problem-solving scenarios suggested that students of the two ability groups demonstrated differential ability to translate their knowledge into cognitive behaviors. The high-ability students more often used well-integrated prior knowledge to produce higher-level thinking. For example:

> HA1:Do the leaves have pores? Ah....water will evaporate from the pores!(HA1,B,25) [The plant would then weigh less] (HA1,B,26), but very slightly (HA1,B,27).

The student was able to access the prior knowledge that there are pores on the surface of leaves, and that water evaporates from the surface of the leaves (HA1,B,25). This prior knowledge was considered to be well-integrated since it defined the relationship between water loss and plant structure. The student's accurate use of this knowledge to make a prediction suggested the ability to synthesize information from various sources to create a coherent perspective (HA1,B,26; HA1,B,27). Another high-ability student also demonstrated the ability to utilize well-integrated prior knowledge into high-level cognitive behaviours. For example:

> HA3:The plant may bend towards [both of the] light sources (HA3,A,36). Up until the half way point, then the leaves will start turning towards the light source to the right (HA3,A,37). [The plant] has to grow. It has to keep growing this way (HA3,A,38).

This student was able to identify and access the prior knowledge that plants tend to bend toward the light source (HA3,A,36). This prior knowledge is well-integrated since it linked together concepts that plants need light for growth and the presence of light will alter the manner in which plants will grow. Furthermore, the student was able to use this knowledge to specify the way in which the plant will grow (HA3,A,37) and subsequently evaluated the conditions, and concluded that the plant had to grow in the proposed manner (HA3,A,38).

Similarly, this student used well-integrated prior knowledge to exhibit higher-level thinking in another problem-solving scenario. For example:

> HA3:[The plant would weigh less] because of the evaporated water (HA3,B,13). Water evaporates from the surface of the leaves (HA3,B,14). If there is no bag around it, then most of the water even before it gets to the plant is going to evaporate (HA3,B,15).

This student had well-integrated knowledge that water evaporates from the surface of the leaves (HA3,B,14), and was able to predict that the weight of the plant would decrease (HA3,B,13). Furthermore the student was able to use the prior knowledge in making an evaluation about the given conditions of the problem-solving scenario. He suggested that if the conditions were different, the prediction made would have been different. This student demonstrated the ability to consider the given conditions carefully and integrate the given conditions with his prior knowledge in a prediction-making scenario.

Contrary to the high-ability students, the average-