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ELEMENTARY SCHOOL STUDENTS' IDEAS ABOUT WATER TRANSPORT IN PLANTS

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Abstract. *Research into students' ideas showed that students' interpretations of natural phenomena often differ from those of scientists. The aim of this study was to identify elementary level students' ideas about water transport in plants. A questionnaire with three open-ended items and multiple choice question was administered to 591 students from 7 primary schools. Students' ideas were examined in five categories using content analysis technique. The students' responses with sound understanding for the "need for water", for the "water uptake", and for the "water loss" in plants took place in the interval of 2 to 10 percent, 16 to 30 percent, and 2 to 4 percent, respectively. Half of the students' responses showed that the teacher was the main source of information about plants.*
Key words: *water transport, plants, student ideas, elementary science education.*

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Introduction

One of the science topics that low level of understanding among students is plant knowledge. Hershey (2002) reported that plants are the least understood, but most often taken for granted group of important living organisms on the planet. Wandersee & Schussler (1999) introduced the term "plant blindness" to describe widespread lack of awareness and neglect of plants in the United States. Research data show that the majority of students do not understand how plant processes (Bell, 1985; McNair & Stein, 2001; Tunnicliffe & Reiss, 2000; Gatt, Tunnicliffe, Borg & Lautier, 2007).

The current study explores elementary level student comprehension of water transport in plants. For the purpose, plant transport will be defined as "the movement of water and solutes through the plant body" (Raven, Evert & Eichorn, 1999, p. 751). Understanding water transport requires that students comprehend selective permeability at the cellular and organism level. Students should be able to explain why and how certain substances can enter and exit not only cells but also body tissues. Since water gradients are driving forces behind transpiration and water absorption of the roots, they are also essential to grasp water transport in plants. Students explaining water absorption of roots should note that greater root surface area increases water absorption; more detail responses may explain how root hairs enlarge absorption area, serving as the primary source for water and mineral intake into plants. A student who comprehends bulk flow in plants would be able to identify that water and minerals are the materials transported upward from the roots into the shoot system. The sugar produced by photosynthesis in the leaves is transported by bulk transport downward to the roots and other plant parts (Campbell, Reece & Mitchell, 1999).

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Students should also be able to recognize transpiration as the evaporation of water mainly through the stomata. Transpiration is the primary cause for the majority of water movement through a plant from roots to leaves. Because transpiration, although rarely, may occur at other plant parts besides the leaves, this research study will also define transpiration "as the loss of vapor by plant parts" – primarily through the stomata of leaves (Raven et al., 1999, p. 912). If no transpiration occurs, a plant will not suffer water deficiency and its cells will not lose their turgidity, as there is no water loss to the surrounding. It can secure enough water supplies for cellular processes even without transpiration (Salisbury & Ross, 1992).

The few studies that have begun to explore the overlooked but necessary realm of water transport in plants (Barker, 1998; Bell, 1985; Yip, 1998; Mak, Yip & Chung, 1999; Tekkaya, Çapa & Yılmaz, 2000; Zwaag, 2005). Bell (1985) focused on student comprehension of plant function and her study revealed that only 20-33% of fifteen-year-olds use accepted scientific ideas about plant nutrition. Bell reported that not only do students hold alternative ideas about plant nutrition, but also there is a lack of understanding of relationships between the component ideas. Bell also noted that most students were unable to relate the process of photosynthesis to other physical and chemical processes of plants such as water/mineral uptake. Barker's (1998) study of New Zealand students' understanding of water transport had a much narrower focus. He conducted interviews about plants and water uptake with 68 seventeen-year-old students. The survey comprised water entry to plant, water movement within a plant, and water exit in plant. The study revealed an erroneous idea among 48% of interviews that water never leaves a plant.

Yip (1998) examined some basic biological concepts with twenty-six novice biology teachers who had majored in biology, and had no more than three years of teaching experience, and were participating in a course of initial teacher training in Hong Kong. Yip developed a written instrument consists of 67 questions that were derived from twelve life science areas; one of them was water transport in plants. The results showed that only 27% novice teachers were able to correctly address the issue of water transport in plants. Mak et al. (1999) reported the alternative conceptions held by junior secondary science teachers who were taking a course of initial teacher training (N=28), and had no more than five years of teaching experience. About half of the teachers demonstrated the erroneous idea that the water absorbed by a plant was mainly used in photosynthesis. When some of these subjects were asked to elaborate on their answers in the follow-up interview, many of them were able to point out that over 99% of the water absorbed by a plant was used to compensate for the water loss through transpiration. Tekkaya et al. (2000) investigated the biology pre-service teachers' understanding about some biological concepts at three universities in Turkey. The survey, which included two questions about water uptake and transpiration of plants, was conducted with 186 biology preservice teachers. The first question (What is the main effect of water uptake in plants?) was answered correctly by only 19.9% of preservice teachers "Transpiration that occurred in mesophyll cells." The second question (For what does a plant mainly use the absorbed water?) was replied correctly by 22% of participants "By means of transpiration, water loss on the surface of leaves." The rest pointed out the other reasons, such as the photosynthesis process (40.9%), during vegetation (27.4%) and metabolic processes (8.6%).

Zwaag (2005) examined the elementary (grade 5), middle (grade 7, 8), high school (grade 11), undergraduate (freshmen biology majors, college students non-science majors, prospective elementary teachers) and graduate students' (science educators) knowledge about water transport in plants. According to the research results, many students at all grade levels do not understand transpiration, and disproportionate emphasis is placed on photosynthesis as a use for water in plants. While the frequency of students (grades 5, 7, 8, and 11) with sound understanding for the *water uptake* had response rates of 13%, 85%, 15%, and 74% respectively; undergraduates (freshmen, college students, prospective elementary teachers), and graduate students with sound understanding had response rates of 38%, 14%, 43%, and 82%, respectively. High school students, undergraduates (freshmen, college students), and science educators with sound understanding had response rates of 9%, 8%, 4%, and 91% respectively for the *water loss* question and they had response rates of 11%, 8%, 21%, and 45%, respectively for the *need for water* question. However, elementary, middle school students, and prospective elementary teachers displayed a 0 percent frequency of sound understanding responses when addressing *water loss* and *need for water*. Results also indicate that elementary through undergraduate students rely most heavily on their teacher as the main source of information about plants.

The field of plant water relations, which addresses the causes and consequences of the strong dependence of plants on water, is a discipline of central importance for plant physiology and ecology. However, there is a little educational research that helps teachers guide or even identify correct and erroneous ideas about water transport that might be held by students at differing educational levels. Documenting the typical ideas which students bring to the classroom is the first step toward facilitating a progression from novice to expert understanding about water transport in plants. Existing educational researches on student understanding of plants emphasize comprehension of photosynthesis; therefore, the focus for this current research study is the less explored topic of water transport in plants. This current study examines students' ideas about water transport in plants. The aim of this study is to increase teacher awareness of the correct and incorrect ideas about water transport in plants that elementary (grade 5) and middle school (grade 6, 7, and 8) students have. Such knowledge would equip teachers to effectively promote student understanding. Therefore, the general research question for this study is, *what do students of elementary and middle school know about water transport in plants?*

Methodology of Research

Instrument and Data Collection Procedure

This study investigates what students know about water transport in plants using survey questions developed by Zwaag (2005). The questions were open-ended questions and translated into Turkish by researchers. It asks students to respond to three water-transport questions emphasizing the areas of (1) *need for water*, (2) *water uptake*, and (3) *water loss*. Two science educators and two elementary science teachers checked the content validity of questions and agreed that the questions were validated and appropriated to measure the students understanding of the given survey. After comments on the questions were completed, we administered the questions to 128 students from two primary schools in early March 2006. The students, who had participated in the pilot study, did not participant to this sample. The questions used in this study are provided in Table 1.

Table 1. Four survey items used in the study.

Student Survey on Plants

1. Give three reasons why plants need water.

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2. Give three things that determine how much water a plant will take. Explain your answers.

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3. Do you think water ever leaves a plant? Explain your answers.

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....

4. Where did you learn *most* of your information on plants? Put a sign *only one*.

Friend	Computer Game	
Parent	Textbook	
Teacher	Library Book or Magazine	
Television	Looking at Indoor Plants	
Online	Looking at Outdoor Plants	

A total of 591 students from seven primary schools participated in the study. Usually, one of the authors visited the schools and administered the questionnaire. The schools were selected randomly

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from a city of the central region of Turkey. The students were from four different grades; grade 5 (N=148), grade 6 (N=153), grade 7 (N=149), and grade 8 (N=141). The students needed approximately 20-25 min for completion of the questionnaire.

Data Analysis

Written answers on open-ended questions were sorted according to patterns detected among the answers. In order to categorize the answers, a rubric were used by researchers based on the study of Zwaag (2005). The rubric was used to code responses according to typical kinds of answers to each question in accordance to methods of grounded theory (Cresswell, 1998). The rubric used to code responses in categories for the questions of water transport in plants, is given in Table 2. In analyzing data, responses were coded by all authors of the study. In the few cases where our scorings differed we discussed the answers until we agreed on the category to be awarded. In the coding process, the upper 90% of average agreement for open-ended questions was found between the two researchers. This was considered sufficiently acceptable to proceed with coding the full data set.

Table 2. Rubric of response categories for survey of water transport in plants

Category	Definition of Category
I	Expresses unanswered/repeated/unclear/off-topic/incorrect response
II	Uses scientific term/idea with a meaning that might be related but not appropriate to the question
III	Uses an idea similar to the experts', but neither incorporates expert terms nor expert explanations to expand upon the idea or the idea expressed was not emphasized by experts
IV	Expresses aspects of scientifically accepted explanation without key terms or uses key terms without enough explanation to clarify what is meant
V	Identifies and explains key terms in a way that captures a main point expressed by experts

Subjects' responses were analyzed by the number of responses rather than by the number of subjects. The questions regarding *need for water*, *water uptake*, and *water loss* were analyzed separately to avoid unintended information doubling or mixing. Before all responses were placed into piles according to specific ideas expressed and then virtually identical responses were combined. "To live" responses merged with the "not to die" responses. "To stay moist" responses were combined with "not to dry out." These similar categories were then grouped by general theme and entered into a database. For example, all responses indicating some sort of environmental influence on *water uptake* such as light, temperature, humidity, wind, soil water or season were entered in an environmental category. The terms such as rate of photosynthesis, transpiration, turgor, to get carbon dioxide or to produce oxygen were entered in plant function category. Specific grouping of responses by type was the third step in the analysis. For example, some environmental responses addressing *water loss* thoroughly explained the effects of atmospheric humidity on the stoma openings within the leaves while other responses mentioned only the word "weather." Under specific grouping of responses by type, "Don't know" and "left blank" responses were grouped together and called unanswered responses. The occurrence of repeated answers such as "to live, to live, to live" for three reasons a plant needs water led to the creation of a repeated responses grouping. Thus it was categorized one "to live" and two "repeated responses." Unclear responses included responses that did not provide legible or enough information to understand the idea expressed.

Eventually, repeated, unclear, off-topic, and incorrect responses were grouped together and entitled category I. Responses that included scientific terms or ideas that were related to plants but seemed inappropriate for answering the questions were classified as category II responses. Many category III responses expressed an idea similar to the experts', but did not incorporate expert terms or expert explanations to expand upon the idea. Those responses that reflected greater expert thinking than category III responses were categorized as category IV or category V responses. Some of these responses expressed important aspects of the expert explanation without using key terms or used key terms but did not provide enough explanation to clarify expert-level meaning. Typical responses expressing aspects of expert explanation without key terms included "to not wilt" and "for chemical reactions" for *need for water*, "if it's been watered recently, it won't take in as much water" for *water uptake*, and "water evaporates from the leaves" for *water loss*. Typical responses that used key terms but did not provide enough information included "turgor" and "osmotic pressure" for *need for water*, "turgor" and "atmospheric humidity" for *water uptake*, and "evaporation," "stomata," and "transpiration" for *water loss*. The few responses for each question that both identified and explained key terms in a way that captured a main point expressed by experts were identified as category V responses. Sample category V responses include explanations of "photosynthesis" and "movement of nutrients" throughout a plant for *need for water*, explanations of "size", "turgor", and responses to the environmental factors such as "humidity" and "temperature of the air" for *water uptake*, and explanations of transpiration and stomata for *water loss*.

Results of Research

The results for category V, category IV, and category III students' responses are displayed in the following Tables.

Question 1: *Give three reasons why plants need water.*

Experts emphasized that much more water is used for structural support and transport of nutrients (fostered by transpiration) than in photosynthesis.

It should be noted, however, that *need for water* did not ask students to explain key terms; therefore, and the frequencies shown Table 3 represent that percentage of responses with answers for *need for water* also including answers providing an explanation, even though not being asked to do so. The frequency of category V responses was low among the subject responses to the question dealing with *need for water*. The frequency of category V responses increased from grade 5 to 8 from 2, 4, 7, and 10 percent of students' responses. The rates of category IV for grade 5 to 8 were 12, 14, 13, and 16 percent of students' responses, respectively. Students showed reasons such as "photosynthesis", "nutrient transport", and "not to wilt" for need for water without key terms or explanations. Students' responses in category III changed for grade 5 to 8 in the range from 4 to 9 percent of students' responses, and the reason was "to stay moist".

Item 2: *Give three things that determine how much water a plant will take. Explain your answers.*

When addressing water uptake, experts provided more than the requested three factors that influence water uptake. Topics addressed included: transpiration demand (hot/dry environment requires more intake of water than cold/wet environment), plant size (greater size requires greater water intake), growth rate (faster growth demands more water), soil water availability, vapor pressure difference between air and plant, and turgor (wilted plant will take in more water).

The topics addressed in understanding levels categories to the water uptake item are illustrated in Table 4. In category V, the success of students' responses varies between 16 and 30 percent corresponding to grade 5 to 8. In category IV, the success rates of students' responses for grade 5 to 8 change between 22 and 31 percent. Some of the "plant size" responses were regarded as category IV, because it mentioned the topic of size or number of leaves but did not explain the connection between size and water uptake. In category III, the success rates of students' responses for *water uptake* for grade 5 to 8 vary between 5 and 12 percent.

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Table 3. Frequencies and percentages in understanding categories of students' responses for need for water (Grade 5, N=148, *f*=364; Grade 6, N=153, *f*=377; Grade 7, N=149, *f*=410; Grade 8, N=141, *f*=403).

Categories	Themes	Grade 5	Grade 6	Grade 7	Grade 8
		f (%)	*f* (%)	*f* (%)	*f* (%)
V	Transport of nutrients	0 (0)	2 (1)	5 (1)	7 (2)
	For photosynthesis	7 (2)	13 (3)	23 (6)	33 (8)
	Subtotal	7 (2)	15 (4)	28 (7)	40 (10)
IV	Transport of nutrients	16 (4)	20 (5)	3 (1)	16 (4)
	Not to wilt	8 (2)	17 (5)	21 (5)	12 (3)
	For photosynthesis	21 (6)	16 (4)	28 (7)	36 (9)
	Subtotal	45 (12)	53 (14)	52 (13)	64 (16)
III	To stay moist	16 (4)	23 (6)	35 (9)	24 (6)

Item 3: *Do you think water ever leaves a plant? Explain.*

Experts responded to the water loss prompt by identifying the process of transpiration and the function of stomata with ideas such as "Water leaves a plant through transpiration" and "Stomata are the main site for water exit." These ideas were further explained with statements such as "Most stomata are present in the leaves, but some stems have stomata," and "No cuticle is ever closed off completely to water loss." Transpiration happens continuously.

As indicated in Table 5, in category V the frequency of student responses changed between 2 and 4 percent, and "transpiration" was the only reason for water loss in students' responses. In category IV, success rates of student responses for different grades varied between 27 and 33 percent. "Sun evaporates" or "sun dehydrates it" were the reason for water loss, only grade 8 students wrote "through stomata." Success rates of student responses at grade 5 to 8 changed from 25 to 31 percent in category III.

Table 4. Frequencies and percentages in understanding categories of students' responses for water uptake (Grade 5, N=148, f=153; Grade 6, N=153, f=206; Grade 7, N=149, f=210; Grade 8, N=141, f=269).

Categories	Themes	Grade 5	Grade 6	Grade 7	Grade 8
		f (%)	f (%)	f (%)	f (%)
V	Plant Size	9 *(6)*	16 *(8)*	22 *(11)*	36 *(13)*
	Environmental factors	11 *(7)*	8 *(4)*	8 *(4)*	23 *(9)*
	Plant Function	4 *(3)*	13 *(6)*	7 *(3)*	22 *(8)*
	Subtotal	24 *(16)*	37 *(18)*	37 *(18)*	81 *(30)*
IV	Environmental factors (climate)	28 *(18)*	29 *(14)*	44 *(21)*	53 *(20)*
	Plant Size (size/number of leaves)	13 *(9)*	10 *(5)*	15 *(7)*	20 *(7)*
	Plant Function (transpiration rate)	5 *(3)*	6 *(3)*	0 *(0)*	11 *(4)*
	Subtotal	46 *(30)*	45 *(22)*	59 *(28)*	84 *(31)*
III	Species/Type of plant	19 *(12)*	9 *(4)*	19 *(9)*	10 *(4)*
	Plant Function (blooming, turgor)	0 *(0)*	2 *(1)*	4 *(2)*	14 *(5)*
	Subtotal	19 *(12)*	11 *(5)*	23 *(11)*	24 *(9)*

Table 5. Percent frequency of understanding categories of students' responses about water loss (Grade 5, N=148, f=353; Grade 6, N=206, f=299; Grade 7, N=149, f=290; Grade 8, N=141, f=285).

Categories	Themes		Grade 5	Grade 6	Grade 7	Grade 8
			f (%)	f (%)	f (%)	f (%)
V	Transpiration		7 (2)	9 (3)	10 (3)	12 (4)
IV	Sun evaporates/dehydrates it		94 (27)	95 (32)	79 (27)	83 (29)
	Through stomata		0 (0)	0 (0)	0 (0)	10 (4)
		Subtotal	94 (27)	95 (32)	79 (27)	93 (33)
III	From pores of leaves		77 (22)	66 (22)	56 (19)	62 (22)
	Through photosynthesis		14 (4)	9 (3)	23 (8)	25 (9)
		Subtotal	91 (26)	75 (25)	79 (27)	87 (31)

Item 4. *Where did you learn most of your information on plants? Mark only one.*

The responses on question 4 were analyzed students' responses to determine the most common source for students to get information about plants. As can be seen in Table 6, "teacher" (49 percent) was primary information source that gradually declines as grade increases from 5 to 8 grade. "Parent" (17 percent) was secondary information source. Another important information source was "looking at outdoor plants" (12 percent), which was higher than "looking at indoor plants" (3 percent), especially for grade 7 and 8. "Textbook" (7 percent) and "library book or magazine" (6 percent) were less important information sources for students. The other sources such as "friend", "television", "internet", "computer game", and "looking at indoor plants" have had less importance for all grades.

Table 6. Frequencies and percentage of students' responses to sources of information about plants (Grade 5, N=148; Grade 6, N=153; Grade 7, N=149; Grade 8, N=141).

Information sources	Grade 5	Grade 6	Grade 7	Grade 8	Total
	%	%	%	%	%
Parent	10	19	17	22	17
Friend	0	0	1	2	0
Teacher	63	54	40	38	49
Textbook	7	9	1	12	7
Library Book or Magazine	7	6	6	3	6
Television	1	1	3	2	2
Internet	6	2	3	2	3
Computer Game	0	1	1	2	1
Looking at Indoor Plants	2	3	5	2	3
Looking at Outdoor Plants	4	6	24	16	12

*More than one marked responses were not evaluated

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Discussion and Conclusion

The present study provides the evidence of how students of various age groups see water transport in plants. Results showed that students' responses were coded more in category III. However, a small number of responses were coded in category V for all of the questions. These data showed that students have significant problems with the water transport in plants. Previous research into students' understanding of plants (Bell, 1985; McNair & Stein, 2001; Tunnicliffe & Reiss, 2000; Gatt et al., 2007) showed that students of similar all age groups have significant problems with plant processes. Students' concepts about plants have been investigated, only a few aspects of students' on this topic can be compared. For example, water transport in plants was able to correctly address, novice biology teachers in Hong Kong (Yip, 1998). In another study, Barker (1998) indicated that about half of students has an erroneous idea that water never leaves a plant. Other researchers confirm that similar problems with water transport exist among different cultures (Mak et al., 1999; Tekkaya, 2000; Zwaag, 2005). Plants are inseparable parts of each science curriculum, so any information about how students consider water transport in plants can help teachers to improve their educational strategy. Our study provides the first in-depth data about students' ideas of water transport. Future research would provide a deeper understanding of students' ideas about water transport.

Teacher was identified as the main source of knowledge about plants. When considering students spend a lot of time in school with their teacher, it is natural that teacher is main source for students. This is also show the teacher-centered instruction in Turkey. Second source for students was their parents. This is similar to findings of Tunnicliffe and Reiss (2000). Parents spend a lot of time with their children, reading books to them or involving them in everyday things such as gardening (Gatt et al., 2007). Results also showed that a small number of students indicated the textbook, television, internet, computer games as knowledge sources. This is similar to findings of Tunnicliffe and Reiss (2000). Although research indicated that students spend a lot of time in their home (Sönmez, 1998; Budak, 2002), it is appeared that students do not help from these knowledge sources, particularly plants.

From an educational perspective, plants make up a large and basic group of living things and have vital role in the ecosystem (Gatt et al., 2007). However, plants do not move and so do not attract students' attention in the same way as animals (Tunnicliffe, 2001). Therefore, students' experiences when learning about plants in school are mostly indirect although they are critical in the acquisition of an advanced biological knowledge system (Hatano & Inagaki, 1997). We propose educational activities.

Firstly, to improve students' views of living organisms as plants, teachers should encourage their students for direct experiences. For example, Brossard, Lewensteinb, and Bonneyb (2005) showed that direct experiences thorough informal science education increased the knowledge of participants about biology. Also, similar other research studies on informal learning also provided evidence for the positive effects of firsthand experiences on student' knowledge and motivation in science (Gibson & Chase, 2002; Knox, Moynihan & Markowitz, 2003). Following these results, we propose that a students' personal experiences with plant through informal learning, for example, visiting botanical garden can have positive effects.

Secondly, improvements of educational methods in science lessons through problem based learning have been found to be advantageous. Teachers are encouraged to engage students in inquiry based tasks which involve the cognitive processes that scientists use. In addition, some practical recommendations for science teachers are:

1. Science teachers should pay more attention on teaching plants and water transport in plants.
2. Science teachers should addresses practical works such as field trips, visiting botanical gardens.
3. Students' knowledge about plants can be influenced through various plants in schools.

4. Direct observations should be used the biology of plants such as processes of water absorption in roots, water transport in the stem, water loss in plant.
5. Problem-based learning should be used when teaching, for example about plants: Why plants need water? Do plants need how much water? Does plant lose water? Etc
6. Several aspects of biology about plants should be taught. Students need more information about the biology of plants, such as water transport in plants.
7. Experimental teaching strategy should be provided the opportunities for students to enhance their understanding of the water relations in land plants.

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