High School Science Teachers' and Students' Conceptions Related to Osmosis

Jeong-Ae Won[1*] · Young-Hwan Ko[2] · Seoung-Hey Paik[3]

Daejeon Mebong Elementary School[1] · Suhmoon Girls' Middle School[2] · Korea National University of Education[3]

Abstract: In this study, high school science teachers' and students' various conceptions related to osmosis phenomena were compared with and analyzed in relation to the content of science textbooks used in high school science classrooms and college science courses. The questionnaires developed by the researchers were administered to science teachers and students. Differences can be found between the explanations of science textbooks on osmotic pressure and semi-permeable membranes. Many science teachers and students thought of osmotic pressure as 'membrane pressure occurred by the movement of a solvent'. Moreover, the types of teachers of semi-permeable membranes were similar regardless of their academic majors. Many of the teachers thought of a semi-permeable membrane as a membrane that 'passes small-size particles'; however, many students thought of this type of membrane as being 'selectively permeable'. Also, the salt-pickling cabbage phenomenon seemed to cause significant confusion to science teachers and students. These study results show that teachers and students possess various conceptions related to the osmosis phenomena. These different conceptions related to osmosis phenomena might cause confusion and diverse conceptions including misconceptions among teachers and students.

Key words: general high school, attached high school, science high school, osmotic pressure, semi-permeable membranes, osmosis phenomena, biology textbook, chemistry textbook

I. Introduction

Several studies have been presented suggesting that students have difficulty in understanding osmosis and have misconceptions related to it (Amir & Tamir, 1987; Friedler, Amir & Tamir, 1985; Friedler, Sin, 1993; Mcknight & Hackling, 1994; Jeong, 1999; Johnstome & Mahmond, 1980a, 1980b; Murray, 1983; Soyibo, 1983; Odom & Barrow, 1995). Several other studies have searched for solutions to these difficulties (Christianson & Fisher, 1999; Jo & Lee, 1994; Odom & Barrow, 1995; Park, 1998); however, few attempts have been made to find the source of students' misconceptions stemming from teachers' thoughts or teaching methods and explanations in textbooks.

From a biological point of view, osmosis is a way of keeping homeostasis in the inner environment of organisms through adjusting the coming in and going out of material from cells to maintain the life of living organisms. From a chemical point of view, however, osmosis is diffusion phenomena through a semi-permeable membrane. The measurement of solute molecular mass in solutions using osmosis phenomena receives focus in most chemistry textbooks (Ko, Kang, Rye & Paik, 2002). Perhaps, these two different points of view might cause students' misunderstanding and diverse misconceptions of osmosis. Teachers who teach osmosis phenomena may also have different perspectives of the phenomena according to their academic majors. If they have different perspectives, it may result in different judgments concerning osmosis phenomena.

In this study, it is presumed that the difference between the perspectives of biology and chemistry related to osmosis phenomena could be a cause of the difficulties felt when students try to understand the concepts related to osmosis phenomena. Also, it is presumed that the science teachers may have different perspectives resulting from their various academic backgrounds. Furthermore, it is presumed

*Corresponding author: Jeong-Ae Won(nontroppo@paran.com)
**Received on 18 September 2006, Accepted on 9 March 2007

that students' thoughts varied according to the type of high schools they attended and the types of textbooks that they learned from at school. Therefore, in this study the researchers tried to find the thoughts underlying teacher and student conceptions related to osmosis phenomena and to compare these understandings with the explanations found in science textbooks.

II. Research Methods

Methods

The thoughts of teachers and students in regards to osmotic pressure, semi-permeable membranes, and osmosis phenomena were investigated by administering the questionnaire. The researchers prepared cognitive conflict situations for crosschecking of teachers' and students' thoughts in the questionnaire. The cognitive conflict situations were: (a) the phenomenon of salt -pickled cabbage and (b) the role of solute in osmosis.

Instrument Development

Explanations of osmotic pressure and semi-permeable membranes found in the chemistry and biology textbooks used in general high school and college science courses were collected for the questionnaire. There were two types of explanations of both osmotic pressure and three types of explanations of semi -permeable membranes.

The results of analysis of 12 chemistry textbooks and 10 biology textbooks used in high schools and 15 chemistry textbooks and 7 biology textbooks used in college shows that 100% of high school chemistry textbooks, 10% of high school biology textbooks, 87% of college chemistry textbooks, and 28% of college biology textbooks explain osmotic pressure as 'pressure to restrain osmosis'. Therefore, this type of explanation can be said to be more pervasive in chemistry textbooks than biology ones. 60% of high school biology textbooks and 28% of college biology textbooks explain osmotic pressure as 'the force that a membrane receives due to the movement of a solvent'. This type of explanation is not found in chemistry textbooks. Therefore, it can be said that this type of explanation is the perspective of biology textbooks.

In addition, 67% of high school chemistry text books, 60% of high school biology textbooks, 33% of college chemistry textbooks, and 28% of college biology textbooks explain a semi-permeable membrane as a membrane that 'passes only solvents'. This type of explanation, therefore, is pervasive in both chemistry and biology textbooks. 33% of high school chemistry textbooks, 20% of high school biology textbooks, 53 % of college chemistry textbooks, and 14% of college biology textbooks explain the semi -permeable membrane as a membrane that 'passes only small-size particles'. It also can be said that this type of explanation is general in chemistry and biology

Table 1
Types of explanation of osmosis, osmotic pressure, and semi-permeable membrane

Concept	Type of explanation	Explanation example	Textbooks in which the type of explanation can be generally seen
Osmotic pressure	Pressure to restrain osmosis	Extra pressure to be added to the solution to prevent osmosis	Chemistry textbooks
	Pressure which the membrane received due to the movement of a solvent	Pressure of the solvent particle to pass through semi-permeable membrane	Biology textbooks
Semi-permeable membrane	Passes only solvent	A membrane that passes solvent particles but does not pass any solute particle.	Chemistry & biology textbooks
	Passes small-size particles only.	A membrane through which particles of a smaller size than the pore of the semi-permeable membrane can pass.	Chemistry & biology textbooks
	Selectively permeable	A membrane which selectively passes materials	Biology textbooks

textbooks. 30% of high school biology textbooks and 14% of college biology textbooks explain the semi-permeable membrane as 'a selectively permeable membrane' (Ko, Kang, Rye & Paik, 2002). This type of explanation is not found in chemistry textbooks; therefore, it can be said to be a biological perspective (see Table 1).

Ten science teachers who were enrolled in graduate courses helped to inspect initially developed questionnaire sheets for teachers. Based on the analysis results, the multiple-choice questionnaire was greater systemized and the sentences were modified to help understanding. The questionnaire has four questions related to osmotic pressure, four questions related to semi-permeable membranes, and two questions related to osmosis phenomena. Thus, this questionnaire consisted of ten questions for teachers. Brief statements of the reasons for the reply were required to be written under each question.

35 second-grade high school students also helped to inspect the initially developed questionnaire for students. Based on the results of the analysis, the multiple-choice questions related to osmosis phenomena were more finely modified. To help the understanding of the students, the sentences were also modified. The question sheet for students consisted of one question related to osmotic pressure, two questions related to semi-permeable membranes, and two questions related to osmosis phenomena with the blanks for writing the reasons of the answers. Therefore, this questionnaire for students consisted of five questions. The contents of this questionnaire were the same as those of the questionnaire for teachers, but it was reorganized so that students could understand questions easily. For students' exact understanding concerning the questions, teachers explained vocabulary or terms in the questionnaire before students answered the questionnaire sheets.

The final questionnaire was organized after validity verification from three science education experts and seven science teachers. The time needed to answer the questions was approximately 30 minutes. After the recovery of the sheets, the science education experts and the science teachers who attended the validity verification of the questionnaire analyzed the answers.

· Participants

This research was conducted with 165 science teachers working at diverse locations including big cities, small cities, and rural regions. The academic backgrounds of teachers is presented in Table 2.

Student samples were selected from a general high school, an attached high school, and a science high school. One class from the second grade classes in each of the high schools was selected. In total, 101 students were participants in this research. The general high school located in a large city and the students in this school attended were chosen by National Approved Exam results and geographical distribution. The attached high school located in a rural region and students of this school were selected through the schools' own exams. In particular, the science high school was located in the small city. Also, only excellent students wanting to major in science attended this school (see Table 3).

III. Results and Discussion

Teachers' conceptions of osmotic pressure

Table 4 represents teachers' conceptions of osmotic pressure according to educational background. In Table 4, 20-30% teachers thought of osmotic pressure as 'pressure due to osmosis', regardless of their majors. This type of thinking is only a simple interpretation of the term and cannot be regarded as demonstrating that the teachers have a clear concept of osmotic pressure.

As shown in the table, science teachers' conceptions of osmotic pressure differ according to their educational

Table 2
Distribution of teachers' academic majors (N)

Academic major			
Physics	Chemistry	Biology	Earth Science
32	54	56	23

Table 3
Number of participating students by high school type

High school type		
General high school	Attached high school	Science high school
33	30	38

Table 4

Teachers' conceptions of osmotic pressure according to academic major (%)

Conception	Academic major				
	Physics	Chemistry	Biology	Earth	Total
Pressure to prevent osmosis	2 (6.3)	28 (51.9)	9 (16.0)	1 (4.3)	40 (24.2)
Membrane pressure occurred by the movement of a solvent	24 (75.0)	12 (22.1)	30 (53.6)	15 (65.2)	81 (49.1)
Pressure due to osmosis	6 (18.7)	14 (26.0)	17 (30.4)	7 (30.5)	44 (26.7)
Difference of solvent velocity	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Total	32 (100)	54 (100)	54 (100)	23 (100)	165 (100)

background. Teachers who had majored in chemistry show a high tendency toward thinking of osmotic pressure as extra pressure added to the solution to prevent osmosis. This tendency seems to correspond to the types of explanations common in the chemistry textbooks. However, science teachers with majors other than chemistry show a relatively high tendency to think of osmotic pressure as 'membrane pressure due to the movement of a solvent', the perspective taken by biology textbooks. This finding suggests that teachers with majors other than chemistry hold the perspective of biology textbooks concerning osmotic pressure.

Students' conceptions of osmotic pressure

Table 5 represents students' conceptions of osmotic pressure according to the type of high school attended. As shown in the table, 61.3% of the students conceive of osmotic pressure as 'membrane pressure caused by the movement of solvent', indicating that osmosis is generally explained in the path of solvent movement through membrane among biological phenomena. This finding illustrates that the perspective of biology textbooks is more universal than the perspective of chemical textbooks regarding size effects or movement of particles.

As revealed by the table, the general high school and the attached high school students' conceptions of osmotic pressure were similar to those of non-chemistry-major science teachers. Many of these students thought of osmotic pressure as the pressure a membrane receives from the particles of a solvent that passes through the semi-permeable membrane.

Unlike other schools, students attending the science high school possessed a variety of perspectives of osmotic pressure. 34.2% of the science high school students thought of osmotic pressure as 'pressure to prevent osmosis'. In particular, 23.6% of the science high school students thought of osmotic pressure as 'difference in solvent velocity'. This type of thought was not found in teachers' responses. However, this type of thinking is consistent with the thoughts of osmosis as the diffusion of a solvent, and the thought that osmosis would stop when the movement speeds of solvents on both sides of the membrane become the same. This finding indicates that science high school students are more likely to possess a concept related to the dynamic equilibrium of particle than the general and attached high school students. Moreover, this result shows that the general and attached

Table 5

Students' conceptions of osmotic pressure according to high school type (%)

Conception	High School Type			
	General	Attached	Science	Total
Pressure to prevent osmosis	2 (6.1)	0 (0.0)	13 (34.2)	15 (14.9)
Membrane pressure caused by the movement of solvent	23 (69.7)	27 (90.0)	12 (31.7)	62 (61.3)
Pressure due to osmosis	7 (21.2)	3 (10.0)	4 (10.5)	14 (13.9)
Difference of solvent velocity	1 (3.0)	0 (0.0)	9 (23.6)	10 (9.9)
Total	33 (100)	30 (100)	38 (100)	101 (100)

high school students tend to share the common biology textbook perspective of osmotic pressure, whereas the science high school students tend to share the common chemistry textbook perspective.

Teachers' conceptions of semi-permeable membranes

The types of teachers' thinking on semi-permeable membranes were similar regardless of their academic majors (see Table 6).

As shown in the table, 47.9% of the science teachers thought that only small-sized particles could pass through the membrane. A correct definition of the semi-permeable membranes would not say that it passes solvents without regard to the size of particles, since it is defined that the solvent is relatively large proportion to the solute in solution. However, 27.9% of whole teachers thought of semi-permeable membranes as 'selectively permeable'. The researchers thought that the term 'selectively permeable membrane' refers to when an organism selectively chooses materials to allow in through and out through the cell membrane actively using energy (Ko, Kang, Rye & Paik, 2002). Thus, the researchers thought that this perspective of biology textbooks has different meaning with semi-permeable membranes that can observe without life phenomenon.

Students' conceptions of semi-permeable membranes

Table 7 shows that 41.6% of the high school students thought of semi-permeable membranes as selectively permeable membranes. This type of thought was higher among the general high school and science high school students than among the attached high school students. Within the parameters of the present study, we cannot identify the exact reason underlying this difference among school types; therefore, future study to determine this cause would be beneficial.

Semi-permeable membrane is related to particle size and selectively permeable membrane is related to life phenomenon. In the common perspective of chemistry textbooks, a more accurate definition of a semi-permeable membrane is related to particle size; however, many students in the study thought that a semi-permeable membrane was a selectively permeable membrane. This result indicates that students frequently confuse the definition of a semi-permeable membrane with that of a selectively permeable membrane.

Teachers' conceptions of the salt-pickling cabbage phenomenon

The salt-pickling cabbage phenomenon seemed to cause significant confusion among science teachers.

Table 6

Teachers' conceptions semi-permeable membranes according to academic major (%)

Conception	Academic major				
	Physics	Chemistry	Biology	Earth	Total
Passes solvent only	8 (25.0)	9 (16.7)	13 (23.2)	8 (34.8)	38 (23.0)
Passes small-size particles	15 (46.9)	28 (51.8)	31 (55.4)	5 (21.7)	79 (47.9)
Selectively permeable	9 (28.1)	16 (29.6)	12 (21.4)	9 (39.1)	46 (27.9)
Others	0 (0.0)	1 (1.9)	0 (0.0)	1 (4.3)	2 (1.2)
Total	32 (100)	54 (100)	56 (100)	23 (100)	165 (100)

Table 7

Students' conceptions of semi-permeable membranes according to high school type (%)

Conception	High school type			
	General	Attached	Science	Total
Passes solvent only	8 (24.2)	9 (30.0)	6 (15.8)	23 (22.8)
Passes small-size particles	11 (33.3)	12 (40.0)	13 (34.2)	36 (35.6)
Selectively permeable	14 (42.5)	9 (30.0)	19 (50.0)	42 (41.6)
Total	33 (100)	30 (100)	38 (100)	101 (100)

According to Table 8, 44.2% of whole science teachers thought that salt particles pass through the cell membrane. The researchers thought that this type of thinking is the more accurate explanation of the cabbage pickling with salt phenomenon. In particular, the percentage (61.1%) of chemistry-major teachers who answered that salt particles can pass through the cell membrane was higher than that of teachers with other majors.

Kimchi, which is made with salted-cabbage, is a staple Korean food; thus, many of the teachers in the study possessed experience related to pickling cabbage with salt. However, regardless of teachers' majors, the percentage of teachers who answered that the cabbage does not become salty after pickling was 10-25%. As shown in the table, many teachers thought that cabbage pickling is an osmosis phenomenon. Furthermore, they thought that salt could not pass through the cell membrane of the cabbage since it is solute. This result shows that these teachers rely on learned theory than personal experiences when they conceive of the salt pickling cabbage phenomenon.

Students' conceptions of the salt-pickling cabbage phenomenon

Table 9 represents students' conceptions of the salt-pickling cabbage phenomenon.

As shown in the table, in contrast to the teachers, 61.4% of the students in the study thought that cabbage becomes salty due to the increase of the concentration of salt in the cabbage. This response is higher among the students attending the general high school and the attached high school than among those students attending the science high school (see Table 9). 26.3 % of the students from the science high school answered that the cabbage tastes no different when pickled with salt, a higher percentage than that from other high schools. These students' thoughts may have been affected by fact that the definition of a solute states that it cannot pass through semi-permeable membranes. From this result, the researchers infer that the science high school students rely on theory to a greater degree than students from other high schools.

Teachers' conceptions of the role of the solute in osmosis

Many of the teachers thought that the solute plays the role in osmosis of decreasing solvent movement

Table 8

Teachers' conceptions of the cabbage pickling with salt phenomenon according to academic major (%)

Conception		Academic major				
		Physics	Chemistry	Biology	Earth	Total
Salty	Salt particles are outside of cell membrane	12 (37.5)	12 (22.2)	22 (39.3)	6 (26.1)	52 (31.5)
	Salt particles pass through the cell membrane	10 (32.3)	33 (61.1)	19 (34.0)	11 (47.8)	73 (44.2)
	Concentration of the cabbage becomes high	2 (6.2)	2 (3.7)	6 (10.7)	1 (4.4)	11 (6.7)
	Salt particles are between the cellular wall and membrane	0 (0.0)	0 (0.0)	3 (5.4)	0 (0.0)	3 (1.8)
	Total	24 (75.0)	47 (87.0)	50 (89.3)	18 (78.3)	139 (84.2)
Not salty		8 (25.0)	7 (13.0)	6 (10.7)	5 (21.7)	26 (15.8)
Total		32 (100)	54 (100)	56 (100)	23 (100)	165 (100)

Table 9

Students' conceptions of cabbage pickling with salt according to high school type (%)

Response		High school			
		General	Attached	Science	Total
Salty	Salt particles are outside of the cell	3 (9.1)	4 (13.3)	6 (15.8)	13 (12.9)
	Salt particles pass through the cell membrane	2 (6.1)	1 (3.3)	6 (15.8)	9 (8.9)
	Concentration of the cabbage becomes high	26 (78.8)	20 (66.7)	16 (42.1)	62 (61.4)
	Total	31 (93.9)	25 (83.3)	28 (73.7)	84 (83.3)
Not Salty		2 (6.1)	5 (16.7)	10 (26.3)	17 (16.7)
Total		33 (100)	30 (100)	38 (100)	101 (100)

by attracting solvents (See Table 10). The percentage of teachers' revealing this type of thinking was 37.0%. In particular, 50.0% of chemistry-majored teachers thought of the role of the solute in this way. However, 42.9% of biology-majored teachers and 39.1% of earth science-majored teachers thought that solutes play the role in osmosis of replacing the solvent.

The percentage of teachers who thought that the role of the solute is to block the pores of the membrane was 7-22%; however, this belief is a misconception. If the pores of the membrane are blocked by the solute, the movements of the solvent cannot occur on either side of the membrane. The percentage of this kind of thought was higher among non-biology-major teachers than biology-major teachers. Within the parameters of the present study, we cannot identify the exact reason underlying this difference among school types; therefore, future study to determine this cause would be beneficial.

The origin of the thought that 'the solute blocks the pores of the membrane' can be found in the structure of science textbooks. Traditionally, chemistry textbooks deal with osmosis in the unit on 'Solutions'.

The percentage of teachers who thought the role of a solute as 'to take the place of solvent' was high in biology-major teachers and earth science-major teachers. The percentage of the teachers who thought that the pressure increase is due to the collision of solutes against the membrane was higher for the physics-major teachers than for other-major teachers.

Physical Chemistry by Noggle (1998) explains that osmotic pressure is not caused by the collision of solute molecules against semi-permeable membranes but, rather, is caused by the flowing of solvent through the membrane. According to Table 4, the highest percentage (75%) of physics-major teachers thought that osmotic pressure is the pressure received by the membrane due to solvent movement.

Students' conceptions of the role of solute in osmosis

Four students attending the attached high school did not answer the question involving the role of solute in osmosis. Thus, the number of total students was 97 in this category (See Table 11).

As shown in the table, many students in the study

Table 10

Teachers' conceptions of the roles of the solute in osmosis according to academic major (%)

Conception	Academic major				
	Physics	Chemistry	Biology	Earth	Total
Replace the place of solvent	9 (28.1)	12 (22.2)	24 (42.9)	9 (39.1)	54 (32.7)
Blocks the pores of membrane	7 (21.9)	10 (18.5)	4 (7.1)	4 (17.4)	25 (15.2)
Increases the pressure by colliding against the membrane	6 (18.8)	3 (5.5)	4 (7.1)	2 (8.8)	15 (9.1)
Decreases solvent movement by attracting solvent	9 (28.1)	27 (50.0)	19 (33.9)	6 (26.1)	61 (37.0)
Others	1 (3.1)	2 (3.8)	5 (9.0)	2 (8.6)	10 (6.0)
Total	32 (100)	54 (100)	56 (100)	23 (100)	165 (100)

Table 11

Students' conceptions of the roles of the solute in osmosis according to high school type (%)

Conception	High school type			
	General	Attached	Science	Total
Takes the place of the solvent	4 (12.1)	6 (23.1)	13 (34.2)	23 (23.7)
Blocks the pores of the membrane	15 (45.5)	6 (23.1)	6 (15.8)	27 (27.8)
Increases the pressure by colliding against the membrane	6 (18.2)	7 (26.9)	4 (10.5)	17 (17.5)
Decreases solvent movement by attracting solvents	7 (21.2)	6 (23.1)	14 (36.8)	27 (27.8)
Others	1 (3.0)	1 (3.8)	1 (3.8)	3 (3.1)
Total	33 (100)	26 (100)	38 (100)	97 (100)

held misconceptions concerning the role of solute in osmosis: 27.8% of students held the misconception that 'solutes block the pores of the membrane'. In addition, another 27.8% of the students thought that the role of solute was to 'decrease solvent movement by attracting solvent'. Future study aimed at finding the reason why the students possess these misconceptions is necessary.

IV. Conclusions and Implications

This study was to investigate teachers' and students' thoughts concerning conceptions related to osmosis phenomena and to compare these understandings with the explanations found in science textbooks.

To understand osmosis, clear definitions of the concepts of osmotic pressure and semi-permeable membranes are necessary. Chemistry textbooks and biology textbooks, however, give different definitions of these phenomena. In particular, biology textbooks present the semi-permeable membrane as having the same meaning as the cell membrane, a selectively permeable membrane, which creates much confusion among the teachers and students when they try to understand the phenomenon of cabbage pickling with salt. The confusion of the membrane definition seems to be a cause of the confusion of osmosis definition. Students tend to think that the cause of osmosis is the difference between solution concentrations on each side of membrane, and when the concentrations become the same that osmosis stops. This perception misses the fact that solutes cannot pass through the membrane. For example, when there is pure solvent on one side of membrane, although this solvent passes through semi-permeable membrane, it cannot become the same concentration on both sides.

Also, the subjects did not show consistency in their perceptions of some phenomena related with osmosis. Some of the teachers and students thought that solutes could be the cause of osmosis, which is 'to block the pores of the membrane' or 'to increase the pressure by colliding with the membrane'. This thought is a misconception that is not consistent with the definitions of osmosis and osmotic pressure.

The results of research show that teachers and students possess their own conceptions concerning osmosis phenomena including various explanations of chemistry textbooks and biology textbooks. The teachers were different distribution of thoughts about osmosis phenomena according to their majors. In particular, physics-major or earth science-major teachers generally follow the perspective of the biology textbooks. Due to this tendency, a high percentage of teachers thought that the salt particles could not pass through the cell membrane when the cabbage is pickled with salt. However, the researchers cannot confirm that teachers' majors affect their thoughts. Therefore, it is necessary to study the reason why the teachers possessed their own conceptions of osmosis phenomena. The students also shared the perspective of biology textbooks. However, the perspective of biology textbooks only focuses on semi-permeable membranes as a cell membrane that can maintain the constancy of living things. This perspective could hinder both the understanding of semi-permeable membranes as a type of material with holes, and of osmosis phenomena caused by this membrane. However, we could not find difference according the students' school types; thus, future research is needed to determine the exact origin of students' conceptions of osmosis phenomena.

References

Christianson, R. G., & Fisher, K. M. (1999). Comparison of student learning about diffusion and osmosis in constructivist and traditional classrooms. Science Education, 21(6), 687-698.

Friedler, Y., Amir, R., & Tamir, P. (1985). Identifying students' difficulties in understanding concepts pertaining to cell water relation: An exploratory study. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching (58th, French Lick Spring, IN, April), 15-18.

Friedler, Y., Amir, R., & Tamir, P. (1987). High school students' difficulties in understanding osmosis. Science Education, 9(5), 541-551.

Jeong, K. S. (1999). An investigation on the secondary biology textbooks' misconception in the definition of vessel·sieve tube·diffusion·osmosis and transpiration·evaporation. A thesis of master degree in Gyeongsang National University. Chinju: Gyeongsang National University Press.

Jo, J. I. & Lee, H. U. (1994); The effectiveness of learning cycle approach based on the model of molecular movement of diffusion and osmosis. Journal of the Korean Association for Research in Science Education, 14(3), 293-303.

Johnstone, A. H., & Mahmoud, N. A. (1980a). Isolating topics of high-perceived difficulty in school biology. Journal of Biological Education, 14(2), 163-166.

Johnstone, A. H., & Mahmoud, N. A. (1980b). Pupils' problems with water potential. Journal of Biological Education, 14(4), 325-328.

Ko, Y. H., Kang, D. H., Ryu, O. H., & Paik, S. H. (2002). Analysis of types on osmosis pressure and semipermeable membrane concept in chemistry and biology textbooks. Journal of the Korean Association for Research in Science Education, 22(3), 444-454.

Mcknight, E. J., & Hackling, M. W. (1994). Students misconceptions of diffusion and osmosis. Proceedings of the 19th Annual Conference of the Western Australian Science Education Association, Perth, November.

Murray, D. L. (1983). Misconceptions of osmosis. In H. Helm and J. D. Novak (Eds.), Proceedings of the international Seminar: Misconceptions in Science and Mathematics (pp. 428-433). New York: Cornell University Press.

Noggle, J. H. (1996). Physical chemistry (3rd ed). New York: Harper Collins College Publishers.

Odom, A. L., & Barrow, L. H. (1995). Development and application of a two-tier diagnostic test measuring college biology students' understanding of diffusion and osmosis after a course of instruction, Journal of Research in Science Teaching, 32(1), 45-61.

Park, K. H. (1998). A Study on the high school students' conceptions and misconceptions of diffusion. A thesis of master degree in Korean National University of Education. Chungbuk: Korean National University of Education Press.

Sin, S. O. (1993). A study on the school students' conceptions and misconceptions of diffusion and osmosis. A thesis of master degree in Jeonnam National University. Gwangju: Jeonnam National University Press.

Soyibo, K. (1983). Selected science misconceptions amongst some Nigerian school students. In H. Helm and J. D. Novak (Eds.), Proceedings of the international Seminar: Misconceptions in Science and Mathematics (pp. 443-445). New York: Cornell University Press.