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Foundations matter: Pre-service teachers' understanding of osmosis and diffusion in relation to their formal science education backgrounds

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Abstract
Osmosis and diffusion are fundamental topics in science education because many processes in nature largely depend on these phenomena. However, many students usually hold misconceptions and have a lack of knowledge about these topics. This study explores pre-service teachers' understanding of osmosis and diffusion in relation to their prior formal education. The main reason for the study was the need to support pre-service teachers so that they can effectively teach these topics. A total of 243 first-year students in bachelor's programs at the University of Ljubljana participated in the study. The results showed that students that graduated from vocational and technical secondary schools had a weaker understanding of these topics compared to students from general secondary schools. Furthermore, only students that had passed the leaving exam in biology showed a better understanding of osmosis and diffusion.

Keywords: diffusion, leaving exam, pre-service teacher, osmosis, Slovenia

INTRODUCTION

Diffusion and osmosis are very important basic science concepts, especially for understanding cell physiology (Odom, 1995; Odom & Barrow, 1995). Diffusion is the primary system of short-distance transport in cells. Molecules within a system tend to continuously disperse or diffuse randomly within the available space due to Brownian motion, but the rate of diffusion can be slow. Many physiological systems (e.g., the transmission of a nerve impulse along a neuron, or the active transport of ions in a cardiac muscle cell) function to reduce reliance on slow rates of diffusion. The systems use energy to move molecules out of random distribution and consequently create diffusion gradients to store energy that cells can then use for other purposes. The direction of molecular diffusion depends on concentration gradients and the size of the molecules. When the gradients are steeper and the molecules are smaller, the rate of diffusion is quicker. The movement of water across a semipermeable membrane from an area of high activity of water to an area of low activity of water is defined as osmosis. Gradients established across the biological membranes are particularly important; they create chemical, electrical, or electrochemical gradients (Moyes & Schulte, 2014). Osmosis is used to explain water uptake by plants, turgor pressure in plants, water balance in aquatic organisms, neuron function, and so on (Odom 1995; Odom & Barrow, 1995).

Misconceptions About Diffusion and Osmosis

Misconceptions refer to a student's view of a scientific concept that is different from the scientifically accepted one (Bekkink et al., 2016). Many students perceive diffusion and osmosis as very difficult school topic (Bahar et al., 1999) and they possess misconceptions about them (e.g., AlHarbi et al., 2015; Malińska et al., 2016; Meir et al., 2005; Odom, 1995; Odom & Barrow, 1995, 2007; Reinke et al., 2020; She, 2004; Tomažič & Vidic, 2012; Torkar et al., 2018). Misconceptions are partially a result of confusion regarding the vernacular and scientific use of terms such as *pressure*, *concentration*, and *quantity*; misunderstanding of technical concepts such as solution, semi-permeability, and molecular and net movement; and insufficient abilities in formal reasoning, visualization, and thinking at the molecular level (Malińska et al., 2016; Odom & Barrow, 1995; She, 2004). Malińska et al. (2016) report that the vast majority of second-year biology students, who stated that they were familiar with osmosis, were unable to define the process

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Contribution to the literature

- The study focuses on pre-service teachers' understanding of osmosis and diffusion in relation to their prior formal education.
- The results show that first-year students had a largely superficial knowledge of the processes of diffusion and osmosis, which is in line with previous studies.
- Students' prior knowledge plays important role in understanding these concepts; students that had passed the biology leaving exam showed a better understanding than those that had passed the chemistry and/or physics leaving exam.

correctly and were unable to indicate the difference between diffusion and osmosis. The most widespread misconception concerning the difference between diffusion and osmosis was the belief that osmosis referred only to water and diffusion to other molecules or only to gases. A widespread misconception among students is a belief that particles move only until concentrations between two environments equalize (Meir et al., 2005; Tomažič & Vidic, 2012) and that the speed of diffusion is not related to differences in solution concentration (Meir et al., 2005). In a recent study by Reinke et al. (2020), first-year cell biology students at an Australian regional university were found to have four key misconceptions:

1. solutes will eventually settle out of a solution,
2. water will always reach the same level,
3. all things expand and contract with temperature, and
4. molecules move only by the addition of an external force.

Reinke et al. (2020) also found no difference in students' understanding of osmosis and diffusion between science and non-science majors among first-year students. Tomažič and Vidic (2012) report that pre-service science teachers in Slovenia only partially understood the random motion of molecules in diffusion and osmosis. The majority of them also incorrectly explained the direction of water flow during osmosis. Torkar et al. (2018) report that Slovene pre-service biology teachers had difficulty choosing the correct animation representing the process of osmosis and providing a correct explanation for their choice.

Teaching About Diffusion and Osmosis

Misconceptions are often extremely difficult to change when traditional learning and teaching methods are used (Malińska et al., 2016; Reinke et al., 2021). Teaching diffusion and osmosis should not be limited to learning disconnected facts (Odom, 1995) or learning these concepts without linking them to already familiar, everyday life processes (Hasni et al., 2016). She (2004) also emphasized that students find it difficult to understand diffusion and osmosis because these concepts require them to visualize and think at the submicroscopic level. AlHarbi et al. (2015) found that pre-service teachers' understanding of osmosis and diffusion concepts had a mild positive correlation with their understanding of particle theory, which suggests that greater attention needs to be invested in teaching particle theory to ensure students' understanding of diffusion and osmosis. There are some studies in which teachers more actively approached the concepts; for example, using computer animations (Reinke et al., 2021; Sung et al., 2017), exercises and experiments (Haddad & Baldo, 2010; Lankford & Friedrichsen, 2012; Odom et al., 2017), a constructivist 5E model (Artun & Costu, 2013), and concept mapping (Kose, 2007).

Research Scope and Focus

The transition into higher education can be very challenging for students (Coertjens et al., 2017). This article focuses on Tinto's (1975) student integration model, which defines six characteristics that strengthen students' academic and social integration into the higher education system. The first characteristic of the model is pre-entry attributes, where the focus is on students' prior schooling. Tinto (1975) asserts that the link between students' characteristics and the institution shapes their engagement and persistence. Many studies have highlighted the importance of students' prior education and experiences upon entering the university level (Birch & Miller, 2007; Bone & Reid, 2011; Hailikari & Nevgi, 2009; Hume & Berry, 2010; Johnson & Lawson, 1998; Lazarowitz & Lieb, 2006; Rayner, 2014; Reinke et al., 2020). The results of these studies indicated that students in science education hold misconceptions that obstruct learning. In other words, a student's good foundation in science education could be an important factor for the level of understanding of science at the university level. However, studies are contradictory in this regard: they range from those that highlight the great importance of prior knowledge and experiences (Rayner, 2014) to those that do not find strong connections (Bone & Reid, 2011).

The pre-service teachers' lack of understanding of osmosis and diffusion that has been reported in previous chapters (e.g., AlHarbi et al., 2015; Artun & Costu, 2013; Tomažič & Vidic, 2012; Torkar et al., 2018) and the need to effectively teach this fundamental science concept to pre-service teachers were the main triggers for conducting this study. Previous studies focused on academic programs, prior experiences with diffusion and osmosis experiments (Tomažič & Vidic, 2012), educational approaches (Artun & Costu, 2013), knowledge progress from the primary to undergraduate tertiary level (Torkar et al., 2018), particle theory conceptions (AlHarbi et al., 2015), and how these factors influence students' knowledge level about diffusion and osmosis. Coley and Tanner (2015) report that students' educational background influenced their science knowledge in tertiary education. In contrast, Reinke et al. (2020) found no difference in students' understanding of osmosis and diffusion between science and non-science majors among first-year students.

The overarching goal of this study was to investigate Slovenian pre-service teachers' understanding of diffusion and osmosis in relation to their formal science education backgrounds. This is an important issue in planning enrollment conditions for academic programs that educate teachers. This was also one of the main reasons for conducting this study. Specifically, four research questions (RQs) were formed:

1. **RQ1:** How well do Slovenian pre-service teachers understand diffusion and osmosis?
2. **RQ2:** Do science major pre-service teachers have different perceptions of diffusion and osmosis than non-science major teachers and, if so, how?
3. **RQ3:** Does pre-service teachers' knowledge of diffusion and osmosis differ depending on whether they completed general education or vocational and technical education programs in secondary education and, if so, how?
4. **RQ4:** Does pre-service teachers' knowledge of diffusion and osmosis differ depending on whether they passed the leaving exam in biology, physics, or chemistry and, if so, how?

METHODS

Research Design

The research design was both quantitative and qualitative. A knowledge test was applied to study pre-service teachers' understanding of diffusion and osmosis. The science problem of diffusion and osmosis (reported here) is one of six science problems that were tested in the project Inquiry-Based Learning of Current Research Topics and Identification of Gifted Students, which was financed by the Slovenian Research Agency. This was a broader project on pre-service teachers' understanding of science concepts. A qualitative approach was applied to analyze open-ended questions.

Sample

The participants (n=243) included cohorts of pre-service teachers in bachelor's programs at the University of Ljubljana (Slovenia). All participating students were in their first year of studies. The sample details are presented in **Table 1**. Students were divided into two groups: science majors (bold) and non-science majors. The students in science majors are pre-service teachers of one or two science subjects (biology, chemistry, and/or physics) and the students in non-science majors are other pre-service teachers. Students are able to enroll in all academic programs at the University of Ljubljana's Faculty of Education with a general leaving exam, and in some cases also with a vocational leaving exam.

Table 1. Description of the participants

Variables	f	f%
Sex		
Male	23	9.5
Female	220	90.5
Age		
19	110	45.3
20	94	38.7
21	27	11.1
22	2	0.8
23	4	1.6
24	2	0.8
26	1	0.4
Missing information	**3**	**1.2**
Academic program **(science major)**		
Art pedagogy	17	7.0
Preschool education	32	13.2
Primary teacher	82	33.7
Social pedagogy	38	15.6
Special and rehabilitation pedagogy	18	7.4
Two-subject teacher		
Biology and chemistry	21	8.6
Biology and home economics	8	3.3
Physics and chemistry	1	0.4
Physics and mathematics	11	4.5
Mathematics and computer sciences	2	0.8
Mathematics and technical education	4	1.6
Home economics and chemistry	5	2.1
Missing information	2	0.8
Type of secondary school		
General education	191	78.6
Vocational and technical education	48	19.8
Missing information	4	1.6
Leaving exam in:		
Biology	36	14.8
Chemistry	43	17.7
Physics	23	9.5

These exams are required to graduate from secondary school and gain admission to the university. Secondary education includes

1. general education with various types of four-year programs, in which students must pass the general leaving exam to graduate and
2. vocational and technical education with programs of varying levels of difficulty (from two to five years) in which students must pass the general

leaving exam or vocational exam in order to graduate.

The general leaving exam consists of five subjects, of which students can choose up to two science subjects, and the vocational exam consists of four subjects with up to one science subject (Eurydice, 2019).

All participants had not been taught about topics connected with osmosis and diffusion at the university before and while performing this study. However, they had learned about these topics in primary and secondary school. Solutions and their properties are covered in greater detail in seventh-grade science in primary school (Skvarč et al., 2011) and in eighth-grade biology class, where students learn that cells exchange molecules with their environment through the cell membrane (Vilhar et al., 2011). Students in general, vocational, and technical secondary schools learn about diffusion and osmosis, but only in general secondary school is this topic an extensive part of the compulsory modules *cell structure and function*, and *structure and function of humans and other animals* (Vilhar et al., 2008a, 2008b). They learn about the selective permeability of the membrane and the basic pathways by which molecules pass through the membrane. They also learn that cell size is limited by the diffusion rate and about the role that diffusion and osmosis play in the respiratory, urinary, and nervous systems. Secondary students may take the elective module *cell biology*, in which they perform hands-on experiments that explain the processes of diffusion and osmosis (Vilhar et al., 2008a, 2008b). In secondary school, students also learn about the properties and motion of molecules in chemistry and brownian motion in physics (Bačnik et al., 2008; Planinšič et al., 2015). In vocational and technical schools, the main goal is more focused on specialization for a particular profession and not on the acquisition of general science knowledge.

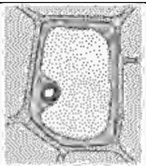
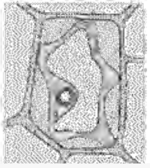
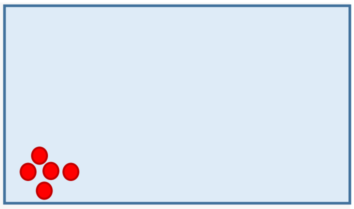
In vocational and technical schools, the compulsory module of the biology subject deals with diffusion and osmosis in one learning objective–knowledge of basic homeostatic mechanisms. Recommended activities include studying the passage of substances across the semipermeable cell membrane. They also learn about membrane permeability in the cell biology elective module. In the human biology elective module, they learn about the role diffusion and osmosis play in the respiratory, urinary, and nervous systems (Zupančič et al., 2007). The amount of attention given to science education in vocational and technical schools depends on the chosen career field, which dictates consideration of elective modules for science subjects. Here, for example, medical and agricultural secondary schools have advantages over technical schools.

Data Sources and Procedure

The study was carried out under the supervision of teaching staff during lectures or laboratory sessions in the 2018/19 academic year. Based on knowledge of the population and the purpose of the study, a purposive sampling technique was used. In purposive sampling, researchers select cases to be included based on their assessment of the typicality or presence of the characteristics sought, thus creating a sample that meets their specific requirements (Cohen et al., 2017). The participants were informed about the purpose of the study prior to answering the questions. First, there were some basic sociodemographic questions and questions about their formal education (see **Table 1**). Next, they answered closed and open-ended questions about science topics.

The tasks analyzed in this study are shown in **Table 2**. Students needed twenty to thirty minutes to answer all the questions. Participation was voluntary and anonymous, and no benefits were offered to the participants. Under Slovenian rules, this kind of survey does not need the approval of an ethical or similar body.

Table 2. Tasks with closed and open-ended questions about diffusion and osmosis

Task				
Task 1: Is the following statement correct? *The picture shows a living plant cell after one hour in distilled water.*		True	False	Do not know
Task 2: Is the following statement correct? *The picture shows a living plant cell after one hour in sugar syrup.*		True	False	Do not know
Task 3: The blue rectangle represents an aqueous solution with salt molecules (represented in red). *Use arrows to mark the direction in which the individual salt molecules will move in the next moment.*				

Data Analysis

All statistical analyses were conducted with IBM SPSS statistics 22. Descriptive statistics (f, f%) were calculated. Pearson's Chi-squared test was used. For tables larger than 2×2, the Chi-square distribution with the appropriate degrees of freedom provides a good approximation to the sampling distribution of Pearson's chi-square when the null hypothesis is true, and "no more than 20% of the expected counts are less than five and all individual expected counts are one or greater" (Yates et al., 1999).

The responses to the open-ended questions (what is diffusion/osmosis?) were transcribed, the ideas contained in the responses were coded into categories, and frequency counts were performed. Coding is an interpretive process by which data are broken down analytically (Corbin & Strauss, 2008). Coding of about 20% of the answers for each open-ended question was performed independently by the first author and corresponding author. Each coder independently proposed categories and then they compared it. Some coding was redefined and added based on discussion between the independent coders and upon earlier published work. Finally, to obviate bias, through discussion, they came to the final version of the rubric. This enabled a 96% reliability rating for the categorization of the analyzed answers.

In the task where an aqueous solution containing salt molecules (task 3) was represented on the picture, students had to use arrows to mark the direction in which the individual salt molecules will move in the next moment. The task was to test their understanding of diffusion and Brownian motion. Their drawings were analyzed using four codes, namely:

1. the length of the arrows,
2. the number of arrows from each particle,
3. the direction of the arrows, and
4. the number of all arrows. Each of these codes was considered a sub-task (task 3A, task 3B, task 3C, or task 3D), which was assessed separately.

Coding of students' drawings was performed independently by the first author and corresponding author. Both classified the students' drawings in the same way.

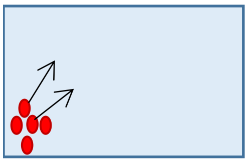
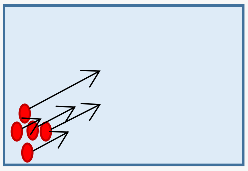
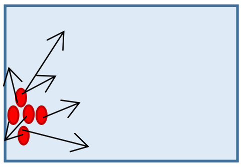
RESULTS

The results for tasks that show a plant cell after one hour in distilled water (task 1) and sugar syrup (task 2) are presented in **Table 3**. The percentages of students with correct (bold), incorrect, and undecided answers are shown. Approximately one-third of students answered both tasks correctly.

Table 3. Results for task 1, representing a living plant cell after one hour in distilled water & task 2, representing a living plant cell after one hour in sugar syrup

Task		True	False	Do not know	Total
Task 1	f	90	26	127	243
	f%	37.0	10.7	52.3	100.0
Task 2	f	78	30	135	243
	f%	32.1	12.3	55.6	100.0

Table 4. Frequencies (f%) of correct & incorrect answers & common misconceptions for task 3 representing the aqueous solution with salt molecules. Correct statements are written in parentheses

Representations (images represent common misconceptions)	Correct	Incorrect
Task 3A. Arrows have the same length. (Correct: Arrows should have different lengths.)	53.5%	46.5%
Task 3B. Only some particles are marked with an arrow. (Correct: Each particle should be marked with an arrow.) 	26.7%	73.3%
Task 3C. Arrows point in the same direction. (Correct: Arrows should point in different directions.) 	8.1%	91.9%
Task 3D. Particles have more than one arrow. (Correct: Each particle should have only one arrow.) 	22.7%	77.3%
Correct answers in total (task 3).	4.1%	95.9%

The task with an aqueous solution containing salt molecules (task 3A, task 3B, task3C, and task 3D) was analyzed in greater detail (**Table 4**). As many as 30% of the students did not provide a response to this task. Among the 70% that provided an answer, the majority (73.3%) did not draw arrows from all the molecules. Specifically, half of them marked only one arrow. The majority (91.9%) drew arrows in the same direction, and half of them (46.5%) drew arrows of the same length. Only 4.1% of the answers were correct overall. **Table 4** presents the frequencies (f%) of correct and incorrect answers and common misconceptions.

Figure 1 presents some of the most common answers by students to task 3.

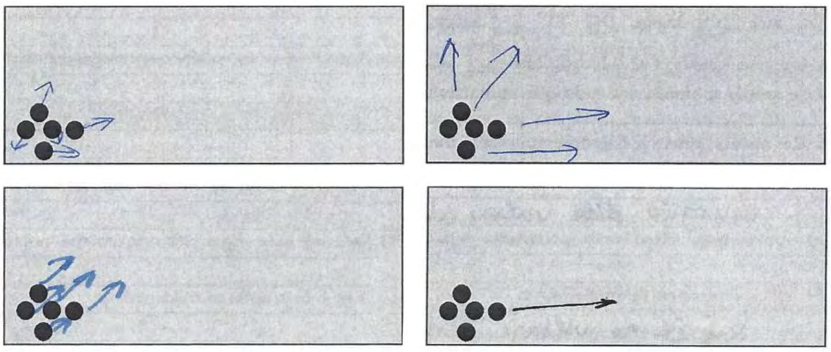


Figure 1. Some students' drawings for task 3 representing the aqueous solution with salt molecules. The upper left picture is correct overall, and the other three pictures present some of the most common misconceptions

Table 5. Categories of student descriptions of osmosis

Categories of student answers	f	f%
Heard of the concept in biology class at school	7	2.9
Something that happens in organisms, in cells	12	4.9
Passage of molecules, particles, substances, or water	58	23.9
Passage of molecules, particles, substances, or water through a membrane between cells	53	21.8
Other answers	7	2.9
No answer	106	43.6
Total	243	100

Table 6. Categories of student descriptions of diffusion

Categories of student answers	f	f%
Heard of the concept in biology class at school	5	2.1
Something that happens in organisms, in cells	3	1.2
Passage of molecules, particles, substances, or water	73	30.0
Passage of molecules, particles, substances, or water through a membrane between cells	35	14.4
Other answers	3	1.2
No answer	18	7.4
Total	106	43.6

Students were also asked to describe osmosis and diffusion in their own words. Their descriptions were categorized as presented in **Table 5** and **Table 6**. Many students did not provide any description of osmosis (43.6%) and diffusion (43.6%). Most frequently they described osmosis as the passage of molecules, particles, substances, or water (23.9%), or the passage of molecules, particles, substances, or water through a membrane between cells (21.8%). Similarly, diffusion was most frequently described as the passage of molecules, particles, substances, or water (30.0%).

We then report pre-service teachers' results in relation to their academic programs (science major or non-science major), type of secondary school education (general or vocational/technical), and leaving exam in science subjects (biology or physics/chemistry). Science major students showed statistically significantly better knowledge about diffusion and osmosis for task 2, task 3B, task 3C, and task 3D (**Table 7**). However, it should be emphasized that the overall percentages of correct answers were low in both groups: the highest was for task 2 (56.3%) for science major students.

The differences in knowledge between students according to whether they had attended a general secondary school or a vocational/technical secondary school are much more pronounced. On all six tasks,

Table 7. Science major and non-science major pre-service teachers' knowledge of diffusion and osmosis

Task	Student		Incorrect	Correct	No answer	Total
Task 1	Science major	f	8	24	16	48
$\chi^2(2)=8.460$		f%	16.7%	50.0%	33.3%	100.0%
p=.015	Non-science major	f	18	66	109	193
		f%	9.3%	34.2%	56.5%	100.0%
Task 2	Science major	f	3	27	18	48
$\chi^2(2)=15.812$		f%	6.3%	56.3%	37.5%	100.0%
p<.001	Non-science major	f	27	51	115	193
		f%	14.0%	26.4%	59.6%	100.0%

Table 7 (Continued). Science major and non-science major pre-service teachers' knowledge of diffusion and osmosis

Task	Student		Incorrect	Correct	No answer	Total
Task 3A	Science major	f	19	21	8	48
$\chi^2(2)=3.705$		f%	39.6%	43.8%	16.7%	100.0%
p=.157	Non-science major	f	63	71	59	193
		f%	32.6%	36.8%	30.6%	100.0%
Task 3B	Science major	f	22	18	8	48
$\chi^2(2)=13.917$		f%	45.8%	37.5%	16.7%	100.0%
p=.001	Non-science major	f	106	28	59	193
		f%	54.9%	14.5%	30.6%	100.0%
Task 3C	Science major	f	32	8	8	48
$\chi^2(2)=14.837$		f%	66.7%	16.7%	16.7%	100.0%
p=.001	Non-science major	f	128	6	59	193
		f%	66.3%	3.1%	30.6%	100.0%
Task 3D	Science major	f	23	14	11	48
$\chi^2(2)=7.534$		f%	47.9%	29.2%	22.9%	100.0%
p=.023	Non-science major	f	109	25	59	193
		f%	56.5%	13.0%	30.6%	100.0%

Table 8. Differences in knowledge between pre-service teachers that graduated from general programs or vocational & technical programs

Task	Type of education		Incorrect	Correct	No answer	Total
Task 1	General	f	22	82	87	191
$\chi^2(2)=20.772$		f%	11.5%	42.9%	45.5%	100.0%
p<.001	Vocational or technical	f	4	5	39	48
		f%	8.3%	10.4%	81.3%	100.0%
Task 2	General	f	30	67	94	191
$\chi^2(2)=17.830$		f%	17.7%	35.1%	49.2%	100.0%
p<.001	Vocational or technical	f	0	9	39	48
		f%	0.0%	18.8%	81.3%	100.0%
Task 3A	General	f	70	76	45	191
$\chi^2(2)=9.658$		f%	36.6%	39.8%	23.6%	100.0%
p=.008	Vocational or technical	f	11	15	22	48
		f%	22.9%	31.3%	45.8%	100.0%
Task 3B	General	f	105	41	45	191
$\chi^2(2)=10.905$		f%	55.0%	21.5%	23.6%	100.0%
p=.004	Vocational or technical	f	22	4	22	48
		f%	45.8%	8.3%	45.8%	100.0%
Task 3C	General	f	133	13	45	191
$\chi^2(2)=10.036$		f%	69.6%	6.8%	23.6%	100.0%
p=.007	Vocational or technical	f	25	1	22	48
		f%	52.1%	2.1%	45.8%	100.0%
Task 3D	General	f	108	35	48	191
$\chi^2(2)=9.652$		f%	56.5%	18.3%	25.1%	100.0%
p=.008	Vocational or technical	f	23	3	22	48
		f%	47.9%	6.3%	45.8%	100.0%

students that had attended a general secondary school showed a statistically significantly better understanding (**Table 8**). Students from vocational or technical secondary schools were more likely to provide no response.

The differences in knowledge between students that passed the leaving exam in biology and those that passed in other subjects are statistically significant for all six tasks, in favor of students who passed the exam (**Table 9**).

Knowledge differences were most significant for task 1 and task 2 (tasks about a plant cell in distilled water and in sugar syrup), which were generally also the most difficult for students to solve. What stands out clearly in the comparison between pre-service teachers who passed the biology leaving exam and those who passed in other subjects is the proportion of students who gave no answer. This is significantly higher for all tasks among students who did not take the leaving exam in biology. Students that did not take the leaving exam in biology were more likely to provide no response.

Table 9. Differences in knowledge between pre-service teachers that passed the biology leaving exam and those that passed in other subjects

Task	Biology exam		Incorrect	Correct	No answer	Total
Task 1	Yes	f	9	23	4	36
$\chi^2(2)=29.998$		f%	25.0%	63.9%	11.1%	100.0%
p<.001	No	f	17	67	123	207
		f%	8.2%	32.4%	59.4%	100.0%
Task 2	Yes	f	8	24	4	36
$\chi^2(2)=34.098$		f%	22.2%	66.7%	11.1%	100.0%
p<.001	No	f	22	54	131	207
		f%	10.6%	26.1%	63.3%	100.0%
Task 3A	Yes	f	12	22	2	36
$\chi^2(2)=13.65839$		f%	33.3%	61.1%	5.6%	100.0%
p=.001	No	f	71	70	66	207
		f%	34.3%	33.8%	31.9%	100.0%
Task 3B	Yes	f	23	11	2	36
$\chi^2(2)=11.543$		f%	63.9%	30.6%	5.6%	100.0%
p=.003	No	f	106	35	66	207
		f%	51.2%	16.9%	31.9%	100.0%
Task 3C	Yes	f	32	2	2	36
$\chi^2(2)=10.867$		f%	88.9%	5.6%	5.6%	100.0%
p=.004	No	f	129	12	66	207
		f%	62.3%	5.8%	31.9%	100.0%
Task 3D	Yes	f	21	11	4	36
$\chi^2(2)=10.383$		f%	58.3%	30.6%	11.1%	100.0%
p=.006	No	f	112	28	67	207
		f%	54.1%	13.5%	32.4%	100.0%

Table 10. Differences in knowledge between pre-service teachers that passed the physics leaving exam and those that passed in other subjects

Task	Physics exam		Incorrect	Correct	No answer	Total
Task 1	Yes	f	2	20	21	43
$\chi^2(2)=3.170$		f%	4.7%	46.5%	48.8%	100.0%
p<.205	No	f	24	70	106	200
		f%	12.0%	35.0%	53.0%	100.0%
Task 2	Yes	f	5	15	23	43
$\chi^2(2)=.188$		f%	11.6%	34.9%	53.5%	100.0%
p<.910	No	f	25	63	112	200
		f%	12.5%	31.5%	56.0%	100.0%
Task 3A	Yes	f	14	18	11	43
$\chi^2(2)=.368$		f%	32.6%	41.9%	25.6%	100.0%
p=.832	No	f	69	74	57	200
		f%	34.5%	37.0%	28.5%	100.0%
Task 3B	Yes	f	25	7	11	43
$\chi^2(2)=.553$		f%	58.1%	16.3%	25.6%	100.0%
p=.758	No	f	104	39	57	200
		f%	52.0%	19.5%	28.5%	100.0%
Task 3C	Yes	f	28	4	11	43
$\chi^2(2)=1.255$		f%	65.1%	9.3%	25.6%	100.0%
p=.534	No	f	133	10	57	200
		f%	66.5%	5.0%	28.5%	100.0%
Task 3D	Yes	f	26	6	11	43
$\chi^2(2)=.693$		f%	60.5%	14.0%	25.6%	100.0%
p=.707	No	f	107	33	60	200
		f%	53.5%	16.5%	30.0%	100.0%

There were no statistically significant differences in knowledge between students that passed the physics leaving exam and those that passed in other subjects (**Table 10**).

There were no statistically significant differences in knowledge between students passed chemistry leaving exam and those that passed in other subjects (**Table 11**).

Table 11. Differences in knowledge between pre-service teachers that passed the chemistry leaving exam and those that passed in other subjects

Task	Chemistry exam		Incorrect	Correct	No answer	Total
Task 1	Yes	f	2	7	14	23
$\chi^2(2)=.754$		f%	8.7%	30.4%	60.9%	100.0%
$p=.686$	No	f	24	83	113	220
		f%	10.9%	37.7%	51.4%	100.0%
Task 2	Yes	f	0	7	16	23
$\chi^2(2)=4.056$		f%	0.0%	30.4%	69.6%	100.0%
$p=.132$	No	f	30	71	119	220
		f%	13.6%	32.3%	54.1%	100.0%
Task 3A	Yes	f	10	9	4	23
$\chi^2(2)=1.676$		f%	43.5%	39.1%	17.4%	100.0%
$p=.433$	No	f	73	83	64	220
		f%	33.2%	37.7%	29.1%	100.0%
Task 3B	Yes	f	13	6	4	23
$\chi^2(2)=1.762$		f%	56.5%	26.1%	17.4%	100.0%
$p=.414$	No	f	116	40	64	220
		f%	52.7%	18.2%	29.1%	100.0%
Task 3C	Yes	f	16	3	4	23
$\chi^2(2)=3.399$		f%	69.6%	13.0%	17.4%	100.0%
$p=.183$	No	f	145	11	64	220
		f%	65.9%	5.0%	29.1%	100.0%
Task 3D	Yes	f	14	4	5	23
$\chi^2(2)=.690$		f%	60.9%	17.4%	21.7%	100.0%
$p=.708$	No	f	119	35	66	220
		f%	54.1%	15.9%	30.0%	100.0%

DISCUSSION

Osmosis and diffusion are important for understanding fundamental concepts of biology and should therefore be studied. In relation to research question 1 (how well do Slovenian pre-service teachers understand diffusion and osmosis?), it was found that first-year students had a largely superficial knowledge of the processes of diffusion and osmosis. Only one in three students correctly solved a task about a plant cell in distilled water (task 1) and a task about a plant cell in sugar syrup (task 2), and almost half of the students did not know the answer. These results are in line with previous studies with pre-service teachers that report superficial knowledge and misconceptions about diffusion and osmosis (AlHarbi et al., 2015; Tomažič & Vidic, 2012; Torkar et al., 2018).

The qualitative part of the study showed that almost half of the students have no idea or do not provide any explanation about osmosis and diffusion. The rest mostly describe diffusion and osmosis as processes at the macroscopic level, such as "transport of water," or at the microscopic level "transport of water in cells," and "transport of particles in cells," but they rarely describe or even do not describe these processes at the molecular level. This shows a misconception which is a result of insufficient ability of thinking at the molecular level. Some students describe both processes with terms concentration, solution, and solvent, but their explanations were mostly not totally correct. Regarding osmosis, they mostly mix terms concentration of solution, concentration of solvent and concentration gradient, such as "transport of liquid from an area of high solvent concentration to an area of low solvent concentration," or their description is not sufficient "transport of water molecules from an area of high concentration to an area of low concentration" and "transport of solvent". This shows their misunderstanding of technical concept (net movement) of this process. Another misconception about diffusion was found regarding the vernacular and scientific use of terms, such as "diffusion of light". All these detected misconceptions about osmosis and diffusion were also highlighted in previous research (Malińska et al., 2016; Odom & Barrow, 1995; She, 2004). Students also mostly know that diffusion and osmosis are somehow related, but they confuse or cannot distinguish between the two processes. Students' answers could be associated with rote learning (learning by heart) which is a technique based on repetition. During rote learning information enters a cognitive structure or may cause interference with previous similar learning. Moreover, rote learning may be recollected for only a short period of time (Ausubel, 1968).

Students' lack of answers also indicates great distrust in their own knowledge of the molecular processes that are fundamental to understanding the natural sciences. Therefore, teaching diffusion and osmosis should be interlinked with various biological processes and other everyday life processes that students are aware of and can experience.

Furthermore, it should be taken into consideration that these concepts require visual representations at the molecular (submicroscopic) level, as already highlighted previously (She, 2004; Tomažič & Vidic, 2012). Making good visual representations is a significant challenge for teachers because inaccurate images can often be the source of misconceptions (Slapničar et al., 2017; Torkar et al., 2018). The task with an aqueous solution containing salt molecules offered better insight into the students' understanding of processes at the molecular level and their abilities to draw representations of the process. Both diffusion and osmosis involve a net movement of particles based on numerous random motions resulting from the collision of particles. The results show that the majority of pre-service teachers did not understand this random aspect of diffusion and osmosis. Students had many misconceptions about the Brownian motion of particles: (i) non-random fluctuation of all particles, (ii) equal velocity, and (iii) preferred direction of flow. Similarly, Garvin-Doxas and Klymkowsky (2008) reported that 95% of K-12 students thought diffusion was a directed motion when a concentration gradient existed, without realizing that it was a net motion based on the random motion of particles. AlHarbi et al. (2015) reported that one-third of pre-service teachers gave the correct answer to the question on particle theory, which is a much better result than in the present study. This could be partly due to the multiple-choice questions used in their study. In addition, they report that pre-service teachers' understanding of osmosis and diffusion concepts and particle theory concepts were positively correlated, suggesting that scores on osmosis and diffusion items increase with scores on particle theory items. Analysis of students' drawings representing the movement of salt molecules in an aqueous solution, task 3 shown in **Table 4**, provided many different insights into students' perceptions of the diffusion process, and so its use is recommended in future diagnostic tests.

Students' prior experiences and higher levels of prior academic achievement may be good predictors of persistence and success at a higher educational level (Bruinsma & Jansen, 2009; Tinto, 1975). This study sought to determine whether prior science knowledge might be important for students' academic performance in basic science topics such as osmosis and diffusion. Some available indicators of prior academic achievement and experience for potential academic success that are or could be used as enrollment criteria in the Slovenian educational system were examined. In relation to research question 2 (do science major pre-service teachers have different perceptions of diffusion and osmosis than non-science major teachers and, if so, how?), students in science and non-science majors were examined on tasks about diffusion and osmosis. It was found that students with science majors had a slightly better understanding of osmosis and diffusion and were more likely to provide an answer than students without science majors. The results of a study by Malinska et al. (2016) indicate that second-year university biology students' knowledge about the processes of diffusion, osmosis, and plasmolysis is poor and fragmented, which testifies to the fact that academic programs in science are not a guarantee for acquiring a scientific understanding of the processes of diffusion and osmosis. The small difference in misconceptions between first-year biology majors and non-majors suggests that advanced secondary-school coursework in biology and/or an interest in life sciences has some effect on biological misconceptions (Coley & Tanner, 2015). Tomažič and Vidic (2012) report that two-subject teachers studying biology and chemistry achieved better diffusion and osmosis diagnostic test results (Odom & Barrow, 1995) than two-subject teachers studying biology and home economics. This suggests that the field of study can influence scientific achievements, even when it comes to different academic science programs.

Concerning research question 3 (does pre-service teachers' knowledge of diffusion and osmosis differ depending on whether they completed general education or vocational and technical education programs in secondary education and, if so, how?), study examined student performance on diffusion and osmosis tasks as a function of type of secondary school attendance. It was found that students that attended vocational and technical secondary schools had a poorer understanding of osmosis and diffusion and were more likely to provide no response than students from general secondary schools. This is consistent with the findings of Birch and Miller (2007). One possible explanation could be the very orientation of the secondary school educational program because in vocational and technical schools the main goal is more focused on specialization for a particular profession and not on the acquisition of general science knowledge. In the compulsory part of biology, only one learning goal deals with diffusion and osmosis (Zupančič et al., 2007). This probably also has implications for the way science is taught–at a more theoretical level, especially in technical schools. Malinska et al. (2016) and Tomažič and Vidic (2012) report that experiments on diffusion and osmosis in upper secondary school positively influenced university students' level of knowledge about these concepts.

One of the most important factors influencing academic achievement at the tertiary level is the result of university entrance examinations (Birch & Miller, 2007; Win & Miller, 2005). This study makes an additional contribution to understanding the importance of leaving or entrance exam results prior to tertiary education. Slovenian students enrolled in teacher education were required to pass a leaving exam, which is required for secondary school graduation and university entrance. In research question 4 (does pre-service teachers' knowledge of diffusion and osmosis differ depending on whether they passed the leaving exam in biology, physics, or chemistry and, if so, how?), the study investigated how their understanding of osmosis and diffusion differs depending on whether they passed or failed the school-leaving examination in biology, physics, and chemistry. The results show that only students that passed the biology leaving exam showed a better understanding of osmosis and diffusion. Surprisingly, however, neither the chemistry nor the physics leaving exams had any significant effect on student performance on the tasks. This is surprising because students learn about Brownian motion in physics in upper secondary school (Planinšič et al., 2015), and submicroscopic representations (e.g., animations of particles) and molecular processes are learned during chemistry already in seventh to ninth grade (Bačnik et al., 2011).

CONCLUSIONS

The purpose of this study was to examine Slovenian pre-service teachers' understanding of diffusion and osmosis in relation to their formal science education backgrounds. Pre-service teachers' prior knowledge plays an important role in their knowledge of these processes. First, students that had passed the biology leaving exam showed better understanding than those that had passed the chemistry and/or physics leaving exam. Next, students that attended vocational and technical secondary schools had less understanding of osmosis and diffusion and were more likely not to provide an answer than general education students. Finally, students with a science major had a slightly better understanding of osmosis and diffusion, and they were even more likely to be able to provide an answer than students without a science major.

First-year students had a largely superficial knowledge of the processes of diffusion and osmosis; that is, poorly understood and fragmented knowledge. It therefore follows from what has been said that misconceptions about diffusion and osmosis need to be identified and addressed in the first year of university study to further improve the knowledge of pre-service teachers. Diagnostic tests on basic science concepts should be used repeatedly in teacher education, and this study provides some exemplary tasks that could be used in testing. This recommendation is particularly important where entry into the academic program is open to students from different types of secondary schools with very different levels of prior schooling and academic success, such as in the Slovenian education system. For pre-service science teachers, understanding the basics is important for developing pedagogical content knowledge (PCK): combining pedagogy and content effectively to make it understandable to learners (Shulman, 1986).

It is important to direct proper attention to teaching approaches and pursue innovations in this area, such as the use of animations and simulations to help students better visualize concepts such as diffusion and osmosis. This would help students alleviate the difficulties in understanding processes at the submicroscopic level that are evident in the results of task 3, in which they had to represent the movement of salt molecules in an aqueous solution. More attention should be paid to the importance of integrative teaching and learning to help students make connections across the curriculum. The knowledge acquired about diffusion and osmosis will enable students to connect the findings of different natural sciences (biology, chemistry, and physics) and everyday experiences (e.g., the importance of diffusion and osmosis in food preservation) and hopefully apply integrated learning principles when addressing other complex, interdisciplinary topics.

This study had some limitations that should be considered when interpreting the results. First, only one generation of prospective teachers from the Faculty of Education at the University of Ljubljana participated in this study, so the results cannot be generalized. Generalization of the results should also be made with caution due to the small sample size of science major students. In a future study, it would be important to collect some additional data (e.g., school grades in science subjects, interest in science subjects) to better understand the background and experiences of students in science education

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REFERENCES

AlHarbi, N. N., Treagust, D. F., Chandrasegaran, A. L., & Won, M. (2015). Influence of particle theory conceptions on pre-service science teachers' understanding of osmosis and diffusion. *Journal of Biological Education, 49*(3), 232-245. https://doi.org/10.1080/00219266.2014.923488

Artun, H., & Costu, B. (2013). Effect of the 5E model on prospective teachers' conceptual understanding of diffusion and osmosis: A mixed method approach. *Journal of Science Education and Technology, 22*(1), 1-10. https://doi.org/10.1007/s10956-012-9371-2

Ausubel, D. P. (1968). *Educational psychology: A cognitive view*. Holt, Rinehart and Winston.

Bačnik, A., Bukovec, N., Poberžnik, A., Požek Novak, T., Keuc, Z., Popič, H., & Vrtačnik, M. (2008). Program srednja šola. Kemija: Gimnazija. Učni načrt. [Secondary school program. Chemistry. Syllabus]. Zavod RS za šolstvo [*Institute of the Republic of Slovenia for Education*]. http://eportal.mss.edus.si/

msswww/programi2018/programi/media/pdf/un_gimnazija/un_kemija_gimn.pdf

Bačnik, A., Bukovec, N., Vrtačnik, M., Poberžnik, A., Križaj, M., Stefanovik, V., & Preskar, S. (2011). Program osnovna šola. Kemija. Učni načrt [Primary school program. Chemistry. Syllabus]. *Zavod RS za šolstvo* [*Institute of the Republic of Slovenia for Education*]. https://www.gov.si/assets/ministrstva/MIZS/Dokumenti/Osnovna-sola/Ucni-nacrti/obvezni/UN_kemija.pdf

Bahar, M., Johnstone, A. H., & Hansell, M. H. (1999). Revisiting learning difficulties in biology. *Journal of Biological Education, 33*(2), 84-86. https://doi.org/10.1080/00219266.1999.9655648

Bekkink, M. O., Donders, A. R., Kooloos, J. G., de Waal, R. M., & Ruiter, D. J. (2016). Uncovering students' misconceptions by assessment of their written questions. *BMC Medical Education, 16*(1), 1-7. https://doi.org/10.1186/s12909-016-0739-5

Birch, E. R., & Miller, P. W. (2007). The influence of type of high school attended on university performance. *Australian Economic Papers, 46*(1), 1-17. https://doi.org/10.1111/j.1467-8454.2007.00302.x

Bone, E. K., & Reid, R. J. (2011). Prior learning in biology at high school does not predict performance in the first year at university. *Higher Education Research and Development, 30*(6), 709-724. https://doi.org/10.1080/07294360.2010.539599

Bruinsma, M., & Jansen, E. P. W. A. (2009). When will I succeed in my first-year diploma? Survival analysis in Dutch higher education. *Higher Education Research and Development, 28*(1), 99-114. https://doi.org/10.1080/07294360802444396

Coertjens, L., Brahm, T., Trautwein, C., & Lindblom-Ylänne, S. (2017). Students' transition into higher education from an international perspective. *Higher Education, 73*(3), 357-369. https://doi.org/10.1007/s10734-016-0092-y

Cohen, L., Manion, L., & Morrison, K. (2017). *Research methods in education*. Routledge. https://doi.org/10.4324/9781315456539

Coley, J. D., & Tanner, K. (2015). Relations between intuitive biological thinking and biological misconceptions in biology majors and nonmajors. *CBE – Life Sciences Education, 14*(1), ar8. https://doi.org/10.1187/cbe.16-11-0317

Corbin, J. & Strauss, A. (2008). *Basics of qualitative research: Techniques and procedures for developing grounded theory*. Sage Publications, Inc. https://doi.org/10.4135/9781452230153

Eurydice. (2019). *Slovenia overview*. https://eacea.ec.europa.eu/national-policies/eurydice/content/slovenia_en

Garvin-Doxas, K., & Klymkowsky M. W. (2008). Understanding randomness and its impact on student learning: Lessons learned from building the biology concept inventory (BCI). *CBE – Life Sciences Education, 7(2)*, 227-233. https://doi.org/10.1187/cbe.07-08-0063

Haddad, H., & Baldo, M. V. C. (2010). Teaching diffusion with a coin. *Advances in Physiology Education, 34*(3), 156-157. https://doi.org/10.1152/advan.00009.2010

Hailikari, T. K., & Nevgi, A. (2009) How to diagnose at-risk students in chemistry: The case of prior knowledge assessment. *International Journal of Science Education, 32*(15), 2079-2095. https://doi.org/10.1080/09500690903369654

Hasni, A., Roy, P., & Dumais, N. (2016). The teaching and learning of diffusion and osmosis. *EURASIA Journal of Mathematics, Science and Technology Education, 12*(6), 1507-1531. https://doi.org/10.12973/eurasia.2016.1242a

Hume, A., & Berry, A. (2010). Constructing CoRes—A strategy for building PCK in pre-service science teacher education. *Research in Science Education, 41*(3), 341-355. https://doi.org/10.1007/s11165-010-9168-3

Johnson, A. M., & Lawson, E. A. (1998). What are the relative effects of reasoning ability and prior knowledge on biology achievement in expository and inquiry classes? *Journal of Research in Science Teaching, 35*(1), 89-103. https://doi.org/10.1002/(SICI)1098-2736(199801)35:1<89::AID-TEA6>3.0.CO;2-J

Kose, S. (2007). The effects of concept mapping instruction on overcoming 9th grade students' misconceptions about diffusion and osmosis. *Journal of Baltic Science Education, 6*(2), 16-25. https://doi.org/10.5539/ies.v6n9p187

Lankford, D., & Friedrichsen, P. (2012). Red onions, elodea, or decalcified chicken eggs? Selecting & sequencing representations for teaching diffusion & osmosis. *The American Biology Teacher, 74*(6), 392-399. https://doi.org/10.1525/abt.2012.74.6.7

Lazarowitz, R., & Lieb, C. (2006). Formative assessment pre-test to identify college students' prior knowledge misconceptions and learning difficulties in biology. *International Journal of Innovation in Science and Mathematics Education, 4*(4), 741-762. https://doi.org/10.1007/s10763-005-9024-5

Malińska, L., Rybska, E., Sobieszczuk-Nowicka, E., & Adamiec, M. (2016). Teaching about water relations in plant cells: An uneasy struggle. *CBE – Life Sciences Education, 15*(4), ar78. https://doi.org/10.1187/cbe.15-05-0113

Meir, E., Perry, J., Stal, D., Maruca, S., & Klopfer, E. (2005). How effective are simulated molecular-level experiments for teaching diffusion and osmosis? *Cell Biology Education*, *4*(3), 235-248. https://doi.org/10.1187/cbe.04-09-0049

Moyes, C. D., & Schulte, P. M. (2014). *Principles of animal physiology*. Pearson.

Odom, A. L. (1995). Secondary & college biology students' misconceptions about diffusion & osmosis. *The American Biology Teacher*, *57*(7), 409-415. https://doi.org/10.2307/4450030

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. https://doi.org/10.1002/tea.3660320106

Odom, A. L., & Barrow, L. H. (2007). High school biology students' knowledge and certainty about diffusion and osmosis concepts. *School Science and Mathematics, 107*(3), 94-101. https://doi.org/10.1111/j.1949-8594.2007.tb17775.x

Odom, A. L., Barrow, L. H., & Romine, W. L. (2017). Teaching osmosis to biology students. *The American Biology Teacher, 79*(6), 473-479. https://doi.org/10.1525/abt.2017.79.6.473

Planinšič, G., Belina, R., Kukman, I., Cvahte, M. (2015). Program srednja šola. Fizika: Gimnazija. Učni načrt. [Secondary school program. Physics. Syllabus]. *Zavod RS za šolstvo* [*Institute of the Republic of Slovenia for Education*]. http://eportal.mss.edus.si/msswww/programi2018/programi/media/pdf/un_gimnazija/2015/UN-FIZIKA-gimn-12.pdf

Rayner, G. (2014). A review of the value of prior learning in first year biology. *International Journal of Innovation in Science and Mathematics Education, 22*(2), 55-63.

Reinke, N. B., Lynn, M., & Parkinson, A. L. (2020). Conceptual understanding of osmosis and diffusion by Australian first-year biology students. *International Journal of Innovation in Science and Mathematics Education, 27*(9), 17-33. https://doi.org/10.30722/IJISME.27.09.002

Reinke, N. B., Lynn, M., & Parkinson, A. L. (2021). Immersive 3D experience of osmosis improves learning outcomes of first-year cell biology students. *CBE – Life Sciences Education, 20*(1), ar1. https://doi.org/10.1187/cbe.19-11-0254

She, H. C. (2004). Facilitating changes in ninth grade students' understanding of dissolution and diffusion through DSLM instruction. *Research in Science Education, 34*(4), 503-525. https://doi.org/10.1007/s11165-004-3888-1

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4-14. https://doi.org/10.3102/0013189X015002004

Skvarč, M., Glažar, S. A., Marhl, M., Skribe Dimec, D., Zupan, A., Cvahte, M., Gričnik, K., Volčini, D., Sabolič, G., & Šorgo, A. (2011). Program osnovna šola. Naravoslovje. Učni načrt. [Primary school program. Science. Syllabus]. *Zavod RS za šolstvo* [*Institute of the Republic of Slovenia for Education*]. https://www.gov.si/assets/ministrstva/MIZS/Dokumenti/Osnovna-sola/Ucni-nacrti/obvezni/UN_naravoslovje.pdf

Slapničar, M., Devetak, I., Glažar, S. A., & Pavlin, J. (2017). Identification of the understanding of the states of matter of water and air among Slovenian students aged 12, 14 and 16 years through solving authentic tasks. *Journal of Baltic Science Education, 16*(3), 308-323. https://doi.org/10.33225/jbse/17.16.308

Sung, S. H. H., Shen, J., Jiang, S., & Chen, G. (2017). Comparing the effects of dynamic computer visualization on undergraduate students' understanding of osmosis with randomized posttest-only control group design. *Research and Practice in Technology Enhanced Learning, 12*(1), 1-21. https://doi.org/10.1186/s41039-017-0067-3

Tinto, V. (1975). Dropout from higher education: A theoretical synthesis of recent research. *Review of educational research, 45*(1), 89-125. https://doi.org/10.3102/00346543045001089

Tomažič, I., & Vidic, T. (2012). Future science teachers' understandings of diffusion and osmosis concepts. *Journal of Biological Education, 46*(2), 66-71. https://doi.org/10.1080/00219266.2011.617765

Torkar, G., Veldin, M., Glažar, S. A., & Podlesek, A. (2018). Why do plants wilt? Investigating students' understanding of water balance in plants with external representations at the macroscopic and submicroscopic levels. *EURASIA Journal of Mathematics, Science and Technology Education*, *14*(6), 2265-2276.https://doi.org/10.29333/ejmste/87119

Vilhar, B., Zupančič, G., Gilčvert Berdnik, D., Vičar M., Zupan, A., & Sobočan V. (2011). Program osnovna šola. Biologija. Učni načrt. [Primary school program. Biology. Syllabus]. *Zavod RS za šolstvo* [*Institute of the Republic of Slovenia for Education*]. https://www.gov.si/assets/ministrstva/MIZS/Dokumenti/Osnovna-sola/Ucni-nacrti/obvezni/UN_Biologija.pdf

Vilhar, B., Zupančič, G., Vičar, M., Sojar, A., & Devetak, B. (2008a). Program srednja šola. Biologija: Splošna gimnazija. Učni načrt. [General secondary school program. Biology. Syllabus]. *Zavod RS za šolstvo* [*Institute of the Republic of Slovenia for Education*]. http://eportal.mss.edus.si/msswww/programi20

20/programi/media/pdf/ucni_nacrti/UN_BIOLOGIJA_gimn.pdf

Vilhar, B., Zupančič, G., Vičar, M., Sojar, A., & Devetak, B. (2008b). Program srednja šola. Biologija: Strokovna gimnazija. Učni načrt. [Vocational secondary school program. Biology. Syllabus]. *Zavod RS za šolstvo* [*Institute of the Republic of Slovenia for Education*]. http://eportal.mss.edus.si/msswww/programi2018/programi/media/pdf/ucni_nacrti/UN_BIOLOGIJA_strok_gimn.pdf

Win, R., & Miller, P. W. (2005). The effects of individual and school factors on university students' academic performance. *Australian Economic Review, 38*(1), 1-18. https://doi.org/10.1111/j.1467-8462.2005.00349.x

Yates, D., Moore, D., & McCabe, G. (1999). *The practice of statistics*. H. Freeman & Company.

Zupančič, G., Vičar, M., Gobec, K., & Mršić, H. (2007). Program srednjega strokovnega in srednjega poklicno-tehniškega izobraževanja. Biologija. [Vocational and technical secondary school program. Biology.]. *Zavod RS za šolstvo* [*Institute of the Republic of Slovenia for Education*]. https://dun.zrss.augmentech.si/#/

https://www.ejmste.com