



# Analysis of Prospective Primary School Teachers' Knowledge Regarding Chemical Representations on Crystallization Experiment

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**ABSTRACT** The study aims to determine the subject matter knowledge of Prospective Primary School Teachers (PPSTs) and analyze their chemical representation levels on crystallization. The study was carried out with descriptive research with a qualitative approach based on this purpose. The study participants were eighty freshman students studying at the Department of Primary Education in a state university in the Aegean Region of Turkey. The data were collected using a worksheet containing seven open-ended questions regarding the crystallization experiment. The questions were about the solubility of salt in water, the formation of the salt water and its solubility-temperature graph, the formation of the saturated salt water, and the appearance of particles formed during crystallization. A worksheet was prepared to determine the chemical representation levels of the PPSTs, and the data were subjected to document analysis. The researchers conducted a demonstration experiment and an animated video on the extraction of table salt by crystallization as an activity during the study process. The results indicated that PPSTs' responses related to crystallization were mainly at the macroscopic level. At the same time, they had great difficulty explaining at the levels of sub-microscopic and symbolic representations. Moreover, they could not explain the concept of dissolution with scientific expressions and distinguish the mixtures from each other. Additionally, most prospective teachers could not draw the correct solubility-temperature graph, so they had difficulty in symbolic representations. The study results imply that to raise the quality of science education in Turkey, PPSTs must attend a quality teaching of science, so primary school students acquire scientifically accurate knowledge of the basic science subjects and concepts such as dissolution, solubility, and crystallization.

**Keywords** Chemical Representations, Prospective Primary School Teachers, Crystallization, Science Education

## 1. INTRODUCTION

The primary education period is the first step where basic education starts, and students acquire various skills, behaviors, and attitudes. Among the main goals of this step is to deliver quality science education. Science is one of the most important fields that uses observation and experimentation to describe and explain natural phenomena. As can be understood, science has a structure that gives more information about the state of things in macroscopic structures. On the other hand, science learning involves observing various natural phenomena and understanding how natural phenomena exist or occur (Merino & Sanmarti, 2008). Thus science courses also challenge teaching students about phenomena that humans often cannot directly interact with. In this case, it becomes difficult to understand due to its complex structure. Therefore, it is extremely crucial to employ representations to realize meaningful learning (Johnstone, 2010; Lindawati, Wardani, & Sumarti, 2019).

When looked at from the point of science, representations have played an essential role in constructing science knowledge because representations convey knowledge many times about objects which humans cannot directly interact with or quickly summarize (Polifka, 2021). Conveying information helps support science processes, including learning (Wu & Puntambekar, 2012) and communication (Kozma, 2003). Students can develop better scientific understanding by engaging in the construction of representation. Representations are essential, especially for students to efficiently learn the basic abstract concepts in scientific fields, differentiate observable and invisible phenomena, and experience correct and meaningful learning in their minds. Suppose we recognize the acts of thinking and interrogating each as a building block of meaningfulness (Aubrey, Ghent, &

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Kanira, 2012). Quality science education can offer students various mental processes to acquire higher cognitive skills and representations. At this point, it is highly crucial to use dynamic analogies (Hermita et al., 2020), activities such as experiments, animations, educational videos (Akkuzu Güven & Uyulgan, 2021), and online activities (Polifka, 2021) to reveal representations and to provide meaningful learning. According to recent studies, these activities help students observe, investigate, and understand the physical world through direct experiences with the phenomena or manipulating objects and materials (Akkuzu Güven & Uyulgan, 2021; Banawi, Sopandi, Kadarohman, & Solehuddin, 2019).

Moreover, primary school teachers are the most important actors who guide science education to ensure that students possess all these acquirements by performing the activities and are raised by the intended goals. The system's success is directly related to teachers' achievement (Knowles, Holton, & Swanson, 2005). Therefore, it is critically important that primary school teachers, and indeed, prospective primary school teachers (PPSTs) have advanced competency in science teaching to ensure a quality process of science learning. Many studies emphasize that this level of education plays a crucial role in raising individuals interested in and exhibiting positive attitudes towards science (Duschl, Schweingruber, & Shouse, 2007; Pine, Messer, & St. John, 2001; Uludüz, 2017). Because the theory of particles is a foundation of the mindset in science education that starts from primary school (Treagust et al., 2010), understanding the microscopic world and establishing its relationship with other representations is essential for meaningful learning to occur. From this point forth, the present study focuses on PPSTs' subject matter knowledge in terms of macroscopic, sub-microscopic, and symbolic levels of chemical representations using demonstration experiments and animated video. Specifically, educators need to identify PPSTs' basic chemistry knowledge through chemical representations. When they start their professional life, they are the only experts who will teach students with in-depth knowledge of the subjects, not superficial, by using various chemical representations. They have a big part in making science courses more real.

In their future professional lives, prospective teachers cannot be expected to teach their students the knowledge and skills that they do not readily have. It is also necessary that they transfer them through practical and meaningful ways. It is therefore crucial that prospective teachers do not have misconceptions and inadequate or inaccurate knowledge of their subject matter (Härmälä-Braskén, Hemmi, & Kurtén, 2020). Primary school teachers administer basic science education starting from the 3<sup>rd</sup> and 4<sup>th</sup> years of primary school. Furthermore, it requires PPSTs to be trained in a way that equips them with the necessary subject matter knowledge related to basic science concepts

(Knowles et al., 2005). It is reported that prospective teachers have inadequate or incorrect knowledge of science concepts in the studies covering the northern part of Turkey (Demircioğlu, Demircioğlu, & Ayas, 2004) and the south-eastern part of the USA (Schulte, 2001). An established finding is that these prospective teachers graduate in an incompetent state of misconceptions and incorrect knowledge of science concepts, resulting in their students carrying similar misconceptions in science (Lemma, 2013). A teacher who is competently knowledgeable in the subject matter will undoubtedly tend to be more self-confident, devoted, and conscious about what and how to teach. Therefore, among the essential characteristics expected of teachers is to possess substantial subject matter knowledge (Aydeniz, Bilican, & Kirbulut, 2017). The initially-acquired knowledge and affective behaviors of science could be had at the early years' stage (Dusch et al., 2007). In this respect, primary school teachers have an essential responsibility. Studies reported that science was one of the least taught subjects at the primary school level. Primary prospective school teachers had mainly negative beliefs about science teaching and had less efficacy for teaching science than for other subjects in the primary curriculum (Buss, 2010; Petersen & Treagust, 2014).

Considering this situation, primary school teachers must be competent in science concepts and ensure that their students acquire this knowledge in a laboratory environment (Kurt & Birinci Konur, 2017). Herga, Čagran, and Dinevski (2016) suggested that laboratory work is the most effective primary method when acquiring science knowledge. Practical work provides students with cognitive processes such as concretizing abstract concepts, problem-solving, analyzing, critical thinking, synthesizing, evaluating, decision making, and creativity (Kurt & Birinci Konur, 2017). According to the current four-year undergraduate curriculum of universities in Turkey, PPSTs are trained about the main concepts of science and science teaching during the courses Basic Science in Elementary School and Teaching Science. Moreover, through the course Laboratory Applications in Science, they become competent at various science experiments to acquire the skill to design experiments suitable for all grades of primary education (Council of Higher Education [CoHE], 2018). However, since they do not have the option to pick among various subject matters for practicing during Practice in Teaching, they graduate with less experience and poor comprehension in teaching science compared to other subject matters of teaching (Mansfield & Woods-McConney, 2012). The current study includes PPSTs who conducted an experiment on crystallization, a physical purification technique in science and is intended to ensure that the participants gain experience for correct and meaningful learning. It is believed that the study might also

help identify the aspects where the prospective teachers are incompetent in crystallization.

It is known that chemistry is the field where students experience comprehension problems the most. It is mainly because most concepts are abstract, and an unfamiliar language is used in chemistry (Barak & Dori, 2004; Eilks & Hofstein, 2015). The concern among science educators about when is the most appropriate time to introduce the concept of particles involving atoms and molecules in the science curriculum is the primary school level (Johnstone, 2010; Tsaparlis, Kolioulis, & Pappa, 2010). Tsaparlis et al. (2010) have suggested delaying the introduction of the concepts of atoms and molecules until such time when students are ready to assimilate these ideas into their cognitive structures. When primary school students have misconception of the basic chemistry concepts such as atom and molecule, they subsequently experience difficulties in comprehending advanced concepts and associating them with the knowledge they were taught previously (Canpolat & Pınarbaşı, 2012).

Additionally, PPSTs have difficulty understanding chemistry because it requires them to transfer between macro (observable, concrete), sub-microscopic (invisible, abstract), and symbolic levels of reaction (Derman & Ebenezer, 2020; Johnstone, 2000). The macro is what can be explained by sense organs; the sub-microscopic is the cognitive model of the matter which is used to explain or predict the properties of substances; and the symbolic is the representation of the macro and sub-microscopic area with symbols (Ye, Lu, & Bi, 2019). Head, Yoder, Genton, and Sumperl (2017) emphasized that in the absence of a chemical representation, pre-service teachers experience difficulty constructing an accurate mental model or internal representation based solely on a text description of abstract chemical concepts.

Johnstone (2000) uses a Chemistry Triangle to symbolize these representations that facilitate comprehension of chemistry knowledge. Johnstone also noted that students' correct comprehension of chemistry concepts occurs within the triangle, not at just one apex of the triangle or along one edge of the triangle. Underlining that expert teachers achieve it as they move fluently across this triad from one representational domain to another, Johnstone recommends that teachers plan to teach students chemical representations by bridging and seeing the connections between the different domains of chemical representations. Jurišević, Glažar, Razdevšek Pučko, and Devetak (2008) reported that a reasonable understanding could be established when all three levels of the concept describe each other in a specific way in students' working memory. It is, therefore, necessary that teachers are aware of the connections between each domain. This cognition will enable the students to construct an appropriate internal representation and connect among these three levels, helping them learn chemical concepts easily.

Recent studies show that primary teachers and teacher candidates have considerable difficulties in understanding the basic science and chemistry concepts, such concepts as chemical and physical changes, dissolution, heterogeneous mixture, and homogenous mixture (Akkuzu Güven & Uyulgan, 2021; Aydeniz, Bilican, & Kirbulut, 2017; Derman & Ebenezer, 2020; Håland, 2010; Härmälä-Braskén et al., 2020; Hermita et al., 2020; Lemma, 2013; Nandiyanto et al., 2018; Sopandi, Kadarohman, Rosbiono, Latip, & Sukardi, 2018; Yerrick & Simons, 2017). Therefore, more studies are needed to explain their chemical knowledge in great detail. This study seeks to determine the PPSTs' subject matter knowledge related to crystallization and analyze their chemical representation levels (macroscopic, sub-microscopic, and symbolic levels) on crystallization.

## 2. METHOD

### 2.1. Research Design

This research is a descriptive study with a qualitative approach. Descriptive research describes the existing situation using scientific procedures to answer real problems. Descriptive data are produced in written or oral words of observed behavior, activities, features, changes, relationships, similarities, and differences between one phenomenon and another. In this type of research, the understanding and meaning of individuals and groups are tried to be described (Creswell, 2012). As this study is descriptive research, it aims to determine and describe the macroscopic, sub-microscopic, and symbolic representation levels of the PPSTs related to the science subject of crystallization, which is one of the methods of separating mixtures. This study is an investigation designed to provide baseline information that will aid and facilitate the development of other complex study strategies.

### 2.2. Participants

The current study participants consisted of first-year students studying at the Department of Primary Education in a state university located in the Aegean Region of Turkey. Participants were selected based on the purposive sampling method that could be very useful when the researcher needs to reach a targeted sample quickly (Creswell, 2012). Due to the limitations in terms of time and labor, this sample is chosen from easily accessible (Yıldırım & Şimşek, 2013). In addition to this choice, the PPSTs have quite similar backgrounds, such as socioeconomic status and grade level. Although they took general chemistry lessons in the first year of high school, they did not take any chemistry or science lessons in the following terms. Therefore, their background concerning science subjects is approximately the same. A total of 80 PPSTs have voluntarily participated in the study. 46 of them were women (57.5%), whereas 34 were men (42.5%). Data were collected within a 2-hour practice in the General Chemistry course taught in the 2018 spring semester. In

order to have the study conform to ethical considerations, all of the prospective teachers were informed about the purpose and process of the research.

### 2.3. Data Collection

The data in the study were obtained through the use of worksheets developed by the researchers. A worksheet on the crystallization experiment was prepared to determine the macroscopic, sub-microscopic, and symbolic representation levels of the PPSTs. Worksheets are written documents containing the process of the activities participants will do in a particular order. These documents ensure the participation of the whole class in the given activity simultaneously. The worksheet consisted of 7 open-ended questions regarding the experiment of crystallization. The questions were about the solubility of salt in water, the formation of the salt water and its solubility-temperature graph, the formation of the saturated salt water, and the appearance of particles formed during crystallization. PPSTs were asked questions about

each representation in open-ended questions, and PPSTs were also asked to draw. Two experts from the Mathematics and Science Education department evaluated the questions for validity and reliability. The final versions of the questions examined within the scope of the research are included in the results section.

### 2.4. Validity and Reliability of Data Collection Tool

In order to provide the validity of the data collection tool, the worksheet questions were evaluated by two experts in terms of content, language, and comprehensibility. The experts scored the questions according to the specified degrees adequate (3), adequate but correction required (2), and not enough (1) (see Table 1).

In order to establish the reliability of the study, the worksheets were analyzed and scored by two researchers independently at different times. The reliability formula of Miles and Huberman (Reliability = Agreement/[Agreement+Disagreement] × 100) was applied to each question of the worksheet form. The agreement percentage representing interrater reliability among researchers was determined as 96%, indicating that the coding was reliable and the coherence excellent (Miles & Huberman, 1994).

### 2.5. Procedure

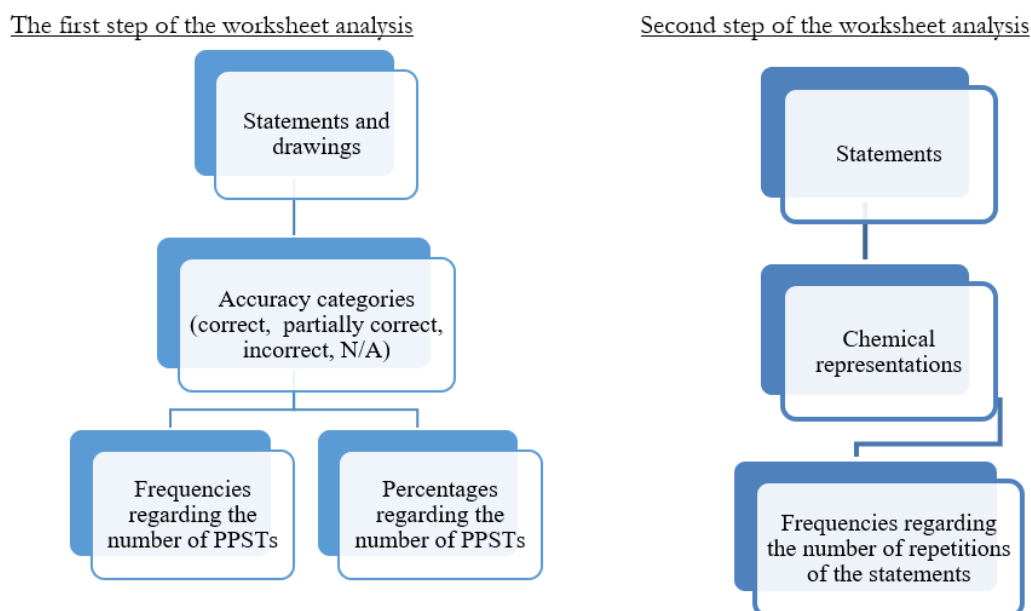
During the data collection process, worksheets related to the crystallization experiment of impure salt were distributed to the PPSTs. The researchers conducted a demonstration experiment on the extraction of table salt by crystallization as an activity for the PPSTs in the classroom environment. Immediately after the experiment, an animated experiment video on the preparation of table salt was shown (see Table 2). The experiment video was chosen according to the level of the PPSTs. In the meantime, they were asked to answer the macroscopic, sub-microscopic, and symbolic questions on the worksheet according to the flow of the experiment.

**Table 1** Evaluation criteria for worksheet's validity

Question number	Expert 1			Expert 2			Total
	Content	Language	Comprehensibility	Content	Language	Comprehensibility	
1	3	3	3	3	3	2	17
2	3	2	3	3	3	3	17
3	3	3	3	3	3	3	18
4	3	3	3	3	3	3	18
5	3	3	2	3	3	3	17
6	3	3	3	3	3	3	18
7	3	3	3	3	3	3	18

**Table 2** The stages of demonstration experiment and animated video experiment

Stages	Demonstration experiment	Animated video experiment
1	15 g of impure table salt is weighed and placed in a beaker containing 50 mL of distilled water.	Some water is taken in a container and heated.
2	The mixture in the beaker is heated up to the boiling temperature.	When water (solvent) starts boiling, some table salt is added slowly.
3	The saturated hot solution is filtered into an Erlenmeyer flask using filter paper and glass funnel and thus separated from water-insoluble impurities.	The mixture is constantly stirred, and salt is added until more salt dissolves in water.
4	The saturated sodium chloride (NaCl) solution is allowed to cool down at room temperature. Then, the solution is left to crystallize.	The saturated solution is filtered into an Erlenmeyer flask using filter paper and a glass funnel. Then, it is allowed to cool down.
5	At the end of crystallization, the crystals formed are washed with pure water.	A stick is taken, and the string is tied to the stick. Finally, the string is placed inside the solution.
6	The crystals formed are filtered and dried in the air.	After a while, large salt crystals suspended are observed to form on the string.



**Figure 1** Step-by-step worksheet analysis

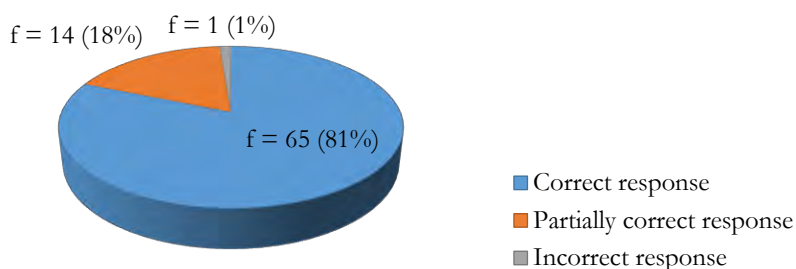
## 2.6. Data Analysis

Documents enable uncovering meaning, developing understanding, and discovering insights relevant to the research problem (Merriam, 1988). Since the worksheet was used as a document in this study, the data were subjected to document analysis. According to this approach, the content of written documents is analyzed systematically (Wach & Ward, 2013). For this purpose, the answers of the PPSTs were firstly examined under chemical representation levels. In order to determine these levels of the PPSTs, the categories were identified in line with their direct statements. For some questions (1, 2, 3, 6a), written responses and drawings were coded according to four categories that were correct, partially correct, incorrect and no answer (N/A) in line with specific criteria (Coştu, Ayas, Çalık, Ünal, & Karataş, 2005). Meanwhile, the answers to the graphic drawing in the 4<sup>th</sup>, 5<sup>th</sup>, and b part of the 6<sup>th</sup> questions were categorized as correct, partially correct, and incorrect drawing. "Correct" responses correspond to the PPSTs' answers that match the scientific knowledge, "partially correct" responses include PPSTs' answers that overlap with scientific knowledge but contain missing information about the question. "Incorrect" responses

include answers that do not correspond to scientific knowledge, and "N/A" means that are not answered or whose responses are meaningless. From the written statements of the PPSTs, not only was it possible to find how they formed associations for the chemical representations, it was possible to discover where they had difficulties related to chemical representations on crystallization. Responses in terms of accuracy categories were analyzed descriptively by frequencies and percentages regarding the number of PPSTs. Also, the analyses concerning the chemical representations were done according to frequencies within the PPSTs' responses. The frequency numbers were the number of repetitions of the statements of PPSTs. Therefore, the total of the frequencies was not equal to the total number of participants ( $N = 80$ ). More or fewer frequencies than the number of participants would be seen in the presented findings tables. Figure 1 shows a step-by-step summary of how to analyze the worksheet.

## 3. RESULTS AND DISCUSSION

In the light of research questions, the PPSTs' responses were first categorized as correct, partially correct, incorrect, and N/A; then, their analyses results were assessed by



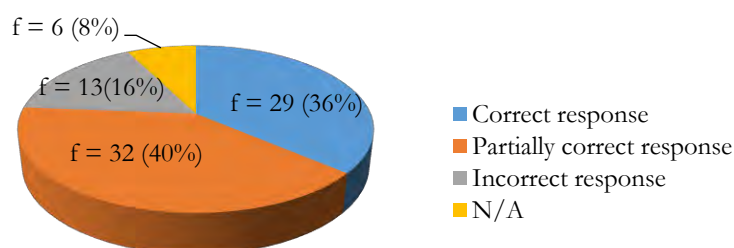
**Figure 2** PPSTs' responses to the first question presented with their frequency and percentage distribution by categories

levels of chemical representations. Finally, the results of their frequency and percentage distribution values were presented descriptively in the following graphs.

The PPSTs were asked the first question, i.e., "How is salt obtained?" and instructed to make necessary explanations. As seen in Figure 2, most of them (81%) responded with correct answers; the rests were 18% partially correct and 1% incorrect. From the analysis results in Table 3, according to the levels of chemical representation, we found that the PPSTs had mostly macroscopic-level statements ( $f = 70$ ). Table 3 shows the chemical representation levels of the PPSTs' responses to this question, along with the relevant sample statements. Among the correct answers given by the PPSTs were evaporating seawater and crystallization, while some of their partially-correct statements also included simple distillation. The first statement that came to the mind of the PPSTs in their responses to how salt was obtained was the method of evaporation of seawater. Crystallization is ranked second among their responses. This result indicates that the prospective teachers only have a casual knowledge of the subject, and they were inadequate to think of practical procedures in terms of chemistry teaching. Laboratory practices are the applications that enable the concretization of abstract concepts. They also allow prospective teachers to discover the associations between the three levels of chemical representations, thereby facilitating better learning. This result is consistent with the study of Kelly, Akaygün, Hansen, and Villalta-Cerdas

(2017), who reported that laboratory experiments could support students' thinking skills. Through these experiments, the students can connect the macro and micro levels of an abstract science concept. Sanchez (2021) also pointed out that implementing strategies such as an experiment-oriented approach can lead a better understanding of the topics as the students visualize the given phenomena. As well as macroscopic level statements, there were some noteworthy answers given at sub-microscopic ( $f = 11$ ) and symbolic ( $f = 2$ ) levels (see Table 2). The sub-microscopic statements explained that salt is obtained through ionic bonding and with the sodium and chlorine atoms compounding. At the same time, their answers of symbolic level referred to the reaction equation of sodium and chloride ions. The answers of these levels revealed that most PPSTs gave the compound of NaCl as an example to refer to salt, which suggests that they perceive salt to be a compound of sodium and chlorine ions.

The second question was intended to investigate how the PPSTs identify crystallization used to purify solids and is one of the production and purification techniques used, especially for saturated salt solutions. As shown in Figure 3, 36% of the PPSTs responded with scientifically correct answers, 40% partially-correct answers, and 16% incorrect answers, and 8% of them had N/A. To consider the analysis results in terms of representation levels, we found that all of the relevant statements were at the macroscopic level (see Table 4). The analysis results in Table 4 revealed



**Figure 3** PPSTs' responses to the second question presented with their frequency and percentage distribution by categories

**Table 3** The results of the analysis of the PPSTs' responses to the first question

Representation Levels	Statements	Frequency values of the statements
Macroscopic	Obtained by evaporating and purifying seawater.	49
	Obtained by crystallizing.	12
	Obtained through simple distillation.	7
	Obtained by grinding rock salt.	2
<b>Total</b>		70
Sub-microscopic	Obtained through ionic bonding.	11
	Obtained with the sodium and chlorine atoms compounding.	
<b>Total</b>		11
Symbolic	Obtained using the equation $\text{Na}^+ + \text{Cl}^- \rightarrow \text{NaCl}$	2
<b>Total</b>		2

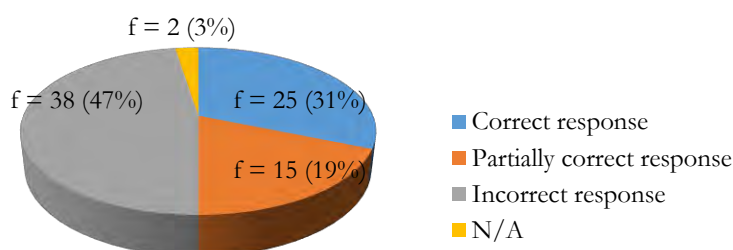
**Table 4** The results of the analysis of the PPSTs' responses to the second question

Representation Levels	Statements	Frequency values of the statements
Macroscopic	It is the evaporation of water.	18
	It is a technique used to distill solid-liquid mixtures.	16
	It is a technique of separating the liquid from the solids through evaporation.	10
	It is to purify solid matters.	9
	It is the extraction of substances like salt and sugar.	6
	It is the transformation of a dissolved liquid into a solid by crystallizing.	5
	It is to freeze and reheat a mixture.	4
	It is the transition phase from gas to solid.	4
	It is a separation technique by using the difference in solubility.	2
<b>Total</b>		<b>74</b>

that most PPSTs described crystallization as the technique where water is evaporated ( $f = 18$ ). This finding might be due to the PPSTs' thoughts that water in salt-water mixture vanishes through evaporation. Similar to this finding, some PPSTs ( $f = 10$ ) described crystallization as the method used to separate liquids from solids through evaporation. These findings indicate that the PPSTs confuse crystallization with evaporation. In response to the second question where we expected them to explain crystallization, the PPSTs answered most, stating that it is water evaporation. This result also shows that the prospective teachers had inadequate knowledge about crystallization, which is one of the separation methods and mostly confused it with the evaporation method. In parallel to this result, Coştu, Ayas, Açıkkar, and Çalık (2007) reported that in response to an open-ended question asking students how they would separate a solid matter dissolved in a solvent from the solvent, majority of the students referred to evaporation as the separation method they would use. We also found out that some PPSTs described crystallization as a technique used to separate solid-liquid mixtures, which concluded that the PPSTs had inadequate knowledge about the technique ( $f = 16$ ). Only a few of the PPSTs' responses contained correct information about crystallization ( $f = 9$ ), while there were also many incorrect answers describing it as the phase transition from gas to solid ( $f = 4$ ) and the phase transition of a dissolved liquid to solid through

crystallizing ( $f = 4$ ). This finding points out that the PPSTs cannot associate crystallization and solubility. The purpose of the crystallization experiment is to explain how the solubility of a solid matter changes depending on the temperature while it is being purified. Therefore, the prospective teachers are required to be knowledgeable about solubility, the phenomenon of dissolving, and the factors affecting solubility. Our results, however, found out that they had incorrect knowledge about the concept of dissolution. Following this result, Taylor and Coll (2002) revealed that pre-service primary teachers could not explain the concept of dissolution with scientific expressions, and they reported that only one of them could explain dissolving in terms of attraction and bonding between molecules. Akkuzu Güven and Uyulgan (2021) stated that the lack of understanding of the prospective primary school teachers in the concepts of mixtures and dissolution might also be due to their insufficient laboratory experience.

We also determined that the prospective teachers could only give mostly macroscopic answers to the questions. Likewise, Derman and Ebenezer (2020) reported that the prospective primary teachers knew physical and chemical changes mainly composed of macroscopic concepts. Moreover, they also revealed the need for the sub-microscopic and symbolic knowledge representations

**Figure 4** PPSTs' responses to question 3a presented with their frequency and percentage distribution by categories

**Table 5** The results of the analysis of the PPSTs' responses to question 3a

Representation Levels	Statements	Frequency values of the statements
Macroscopic	Salt sinks to the bottom.	39
	They form a homogeneous mixture.	21
	They form a heterogeneous mixture.	7
	Salt dissolves in the water and becomes invisible.	7
	Salt becomes visible, and water blurs.	3
<b>Total</b>		<b>77</b>
Sub-microscopic	Salt particles stick to each other and float in the water.	6
	Particles of water and salt are equally dispersed as the solution is homogeneous.	3
	Compared to particles of water, salt particles stay closer to each other.	2
	Salt appears to adhere to water molecules as it is a homogeneous mixture.	3
	Sodium gives 1 electron to chlorine to form an ionic bond.	2
<b>Total</b>		<b>16</b>
Symbolic	Salt $\rightarrow$ NaCl	2
	Water $\rightarrow$ H <sub>2</sub> O	
<b>Total</b>		<b>2</b>

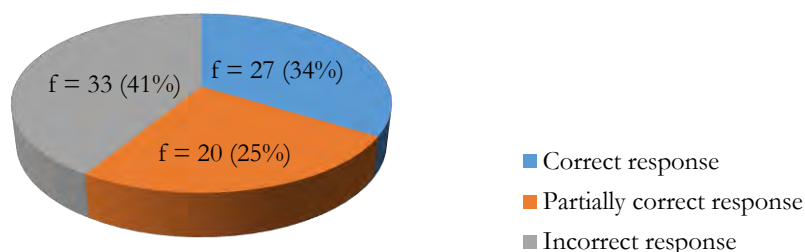
connected with the missing steps of the instructional design.

The third question on the worksheet is composed of three parts of 3a, 3b, and 3c. In the macroscopic question 3a, the PPSTs were asked what they would observe when adding salt into the water in a beaker. Unfortunately, 47% of them had incorrect answers, while only 31% had correct answers; additionally, 19% had partially correct answers; and 3% had N/A (see Figure 4). This is because the PPSTs answered this macroscopic question at sub-microscopic and symbolic levels and were unable to differentiate homogeneous and heterogeneous mixtures.

The results presented in Table 5, considering the PPSTs' chemical representation levels, show that they had responses about other representations while expecting macroscopic answers. This might be because they could not comprehend the differences between representation levels soundly. Among the incorrect answers, some PPSTs stated that salt sinks to the beaker's bottom ( $f = 39$ ), they form a heterogeneous mixture ( $f = 7$ ), and salt particles stay visible in the beaker ( $f = 3$ ). These findings are linked with the inadequate knowledge that the PPSTs have about the

term "dissolution". Our results also demonstrated that the prospective teachers frequently used macroscopic statements such as disappearing and becoming particles invisible to the naked eye while addressing the salt dissolving in water. Studies' results are consistent with this result report that both students and prospective teachers defined the concept of dissolution as the disappearance of the dissolving substance (Demirbaş, Tanrıverdi, Altınışık, & Şahintürk, 2011; Kabapınar, Leach, & Scott, 2004; Tarkın Çelikkıran & Gökçe, 2019). Ye et al. (2019) maintain that due to the abstract idea of the charge of the ions, students cannot "see" at the microscopic level.

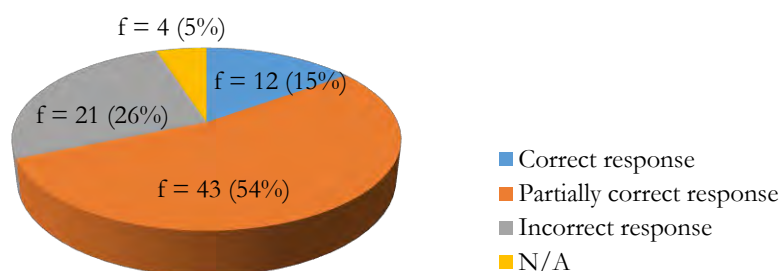
The answers given by the PPSTs to question 3b, "What happens when you heat salt-water mixture?" are shown in Figure 5. The majority of the PPSTs (41%) had incorrect answers. Table 6 shows that the explanations of the PPSTs were at macroscopic and sub-microscopic levels. These statements at the macroscopic level included that salt dissolves in water and becomes invisible ( $f = 24$ ). The previously heterogeneous mixture becomes a homogeneous mixture ( $f = 4$ ). Although their statements are observed to pertain to the macroscopic level, it is also

**Figure 5** PPSTs' responses to question 3b presented with their frequency and percentage distribution by categories



**Table 6** The results of the analysis of the PPSTs' responses to the question 3b

Representation Levels	Statements	Frequency values of the statements
Macroscopic	Salt begins to dissolve in the water and becomes invisible.	24
	Water evaporates, and salt sinks to the bottom.	19
	The previously heterogeneous mixture converts into a homogeneous mixture.	4
	Salt melts in the water.	4
	Salt becomes invisible but keeps its taste.	3
<b>Total</b>		<b>54</b>
Sub-microscopic	The distance between particles is increased.	15
	Water particles slowly drift apart while salt particles get closer because the solids convert into a regular pattern's solid state of matter.	5
	Kinetic energy and, therefore, the movement of particles increase when the temperature rises.	2
	Salt particles ionize.	2
<b>Total</b>		<b>24</b>

**Figure 6** PPSTs' responses to question 3c presented with their frequency and percentage distribution by categories

understood that they have misunderstandings in terms of scientific accuracy. Because they thought that salt dissolves only when heated. Some PPSTs also expressed that water evaporates and salt sinks to the bottom after the heating ( $f = 19$ ). As the answers given by the PPSTs at the sub-microscopic level were examined, the statements pertained to the particulate level. Although the overall number of PPSTs with correct answers at this level was high, others still had incorrect answers stating that salt particles move closer to each other to have an ordered pattern only when heated as salt is solid ( $f = 5$ ).

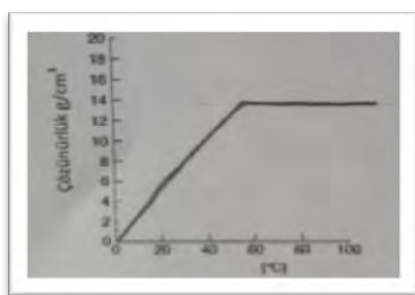
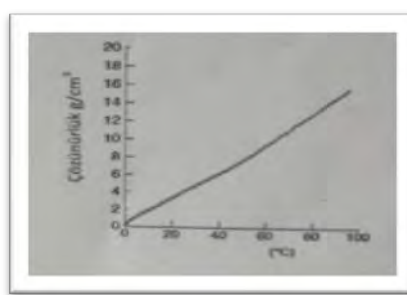
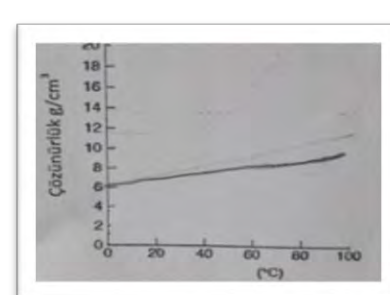
The PPSTs were asked question 3c, "What is the purpose of heating the salt-water mixture?" as part of the crystallization experiment. Only a few of them (15%) had scientifically correct answers to the question, while most (54%) of them had partially-correct answers, 26% had incorrect answers, and the rest (5%) had N/A (see Figure 6). The PPSTs answered this question at macroscopic and sub-microscopic levels according to chemical representations. Although their statements matched the representation levels, there were also scientifically incorrect answers. As in the second question, the PPSTs confused evaporation with crystallization in this question as well ( $f = 22$ ) (see Table 7). Moreover, the PPSTs who stated heating is necessary due to the difference in solubility ( $f = 12$ ) failed

to comprehend that multiple solid substances dissolve in a solvent. Many PPSTs confused melting with dissolving ( $f = 15$ ). There were, however, some other scientifically correct answers stating that heating is necessary to accelerate the dissolving process ( $f = 6$ ) and to increase the amount of salt dissolving in water ( $f = 10$ ). There were also sub-microscopic answers stating that heat is needed to allow particles of salt and water to make a reaction ( $f = 4$ ). This situation reveals that the PPSTs consider dissolving as a chemical phenomenon.

In response to the question on the salt-water mixture, some of the prospective teachers described the mixture as a heterogeneous mixture, and they did not consider the ionic dissolving of salt in their sub-microscopic drawing. The prospective teachers could also not demonstrate the salt ions being surrounded by water molecules while dissolving in their statements and drawings. This result is compatible with the study by Tarkin Çelikkıran and Gökçe (2019), they determined that although prospective chemistry teachers were able to draw a salt consisting of an anionic assembly of cations, anions and water molecules, they could not illustrate the ions being surrounded by water molecules. A similar result is also encountered in the study where Uluçınar Sağır, Tekin and Karamustafaoğlu (2012) included PPSTs. The study concluded that the prospective

**Table 7** The results of the analysis of the PPSTs' responses to the question 3b

Representation Levels	Statements	Frequency values of the statements
Macroscopic	The solution is heated to separate salt from water until the water evaporates.	22
	Salt melts in the water.	15
	We can separate them as they have different solubility values.	12
	Heat facilitates the dissolution of salt in water.	8
	Heat accelerates dissolution.	6
	The amount of salt dissolving in water increases as the solution is heated.	10
<b>Total</b>		<b>73</b>
Sub-microscopic	Heat allows particles of salt and water to make a reaction.	4
	It is needed for ionization so that salt dissolves in water.	3
<b>Total</b>		<b>7</b>

**Incorrect drawing****Partially correct drawing****Correct drawing****Figure 7** Examples of the graphs drawn by the PPSTs in response to the fourth question

teachers had difficulty drawing the phenomenon of salt dissolving in water at the particulate level and determining which of the various mixtures were solutions. Another remarkable result is encountered in the statements of the PPSTs referring that salt and water particles make a reaction when the salt-water solution is heated. The reason why they comprehend the phenomenon of dissolution as a chemical fact might be that they could not observe it at the sub-microscopic level (Okumuş, Öztürk, Doymuş, & Alyar, 2014).

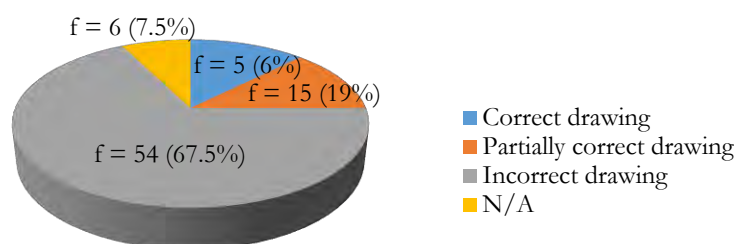
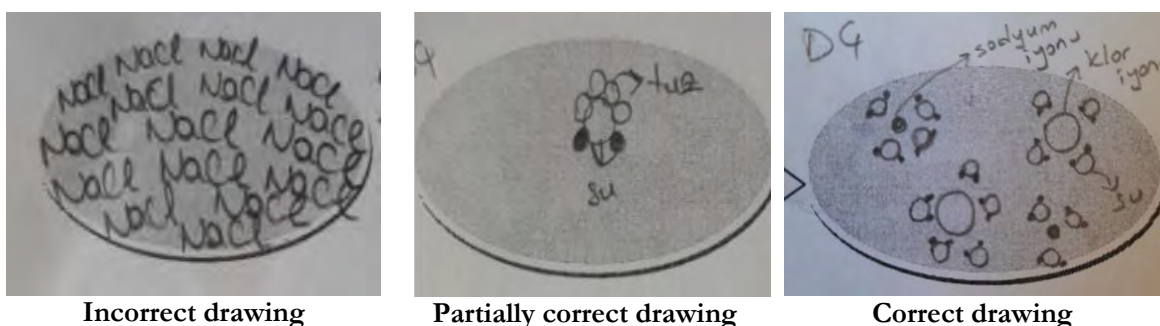
In the fourth question, the PPSTs were asked to draw a solubility-temperature graph to represent the solubility of NaCl in water and to explain the reasoning of their drawings. This question was mainly intended to understand how correctly they could concretize the phenomenon of the salt dissolving in water, which is one of the crystallizing processes, using a graph at the symbolic level. Most PPSTs (75%) had incorrect drawings, while 20% had partially correct and 5% had correct drawings (see Figure 7). Some of the PPSTs with incorrect drawings ( $f = 35$ ) assume that the salt-water solution is pure. Therefore, they confused the solubility-temperature graph with the temperature-time graph. Another reason PPSTs had great difficulty drawing the graph was that they could not think that the solubility-temperature curve continued to increase ( $f = 10$ ). This indicates that they confuse evaporation with boiling.

Finally, some PPSTs ( $f = 12$ ) explained the saturated salt-water solution by rote based on the temperature-time graph. Despite being correct in the case of the temperature-time graph, these explanations were scientifically incorrect for the question asked about the solubility-temperature graph.

The PPSTs with the partially correct drawing could establish that NaCl had a solubility that increased as the temperature increased. However, they took 0 °C as the initial point where solubility presents ( $f = 12$ ). Their statements also revealed that they had miscomprehension about the solubility of salt being directly proportional to temperature ( $f = 4$ ). Moreover, some PPSTs ( $f = 8$ ) had the misunderstanding that salts with solubility, which increases as temperature rises, dissolve in water only to an extent (see Table 8). Therefore, most prospective teachers could not draw the correct solubility-temperature graph for the salt-water solution. This also indicated that the prospective teachers had difficulty in symbolic representations. This is because the prospective teachers were unable to distinguish between pure substances and solutions and had inadequate knowledge about the solubility-temperature graph of the solids whose solubility increases with an increase in temperature. However, graphs are indispensable components of scientific statements (Glazer, 2011). Therefore, symbolic representations such as graphs, tables,

**Table 8** The Results of the analysis of the PPSTs' drawings of solubility-temperature graphs about the solubility of NaCl in water

Levels	f and % values	Statements	Frequency values of the statements
Correct drawing	4 (5%)	Solubility increases as temperature rises.	3
		Solubility changes as the saline solution is a homogeneous mixture, but not much.	1
Partially correct drawing	16 (20%)	There is a maximum amount of substance that water can dissolve. After a while, no matter how much we increase the temperature, the solubility terminates at some point.	8
		The solubility of the salt in water changes directly proportional to temperature.	8
Incorrect drawing	60 (75%)	Water boils at 100 °C and then stays constant.	35
		It remains constant after the saturated solution has occurred.	12
		Solubility remains constant at the temperature where evaporation begins.	10
		Solubility is a distinctive characteristic and therefore remains unchanged.	3
<b>Total</b>	80 (100%)		80

**Figure 8** Distribution of the PPSTs' drawings in response to the fifth question by categories**Figure 9** Examples of the PPSTs' drawings in response to the fifth question

formulas, equations, etc., are crucial for understanding the relations between many science concepts and phenomena (Tepe & Akkuzu Güven, 2020; Taber, 2009). Similar to our results, Gheith and Aljaberi (2015) found that the pre-service classroom teachers had poor graph skills, which is one of the symbolic representations. Therefore, we can conclude that the symbolic level representations provide clues that indicate how accurately a science subject has been learned.

In the fifth question, the PPSTs were asked to explain what changes happen in a mixture when the amount of salt is increased at a specific temperature and to draw an

appearance of the particles of the mixture. Most of them (67.5%) had incorrect drawings in response to this question (see Figure 8). There were only a small number of PPSTs with correct drawing (6%), in addition to some others with no drawing at all (7.5%). For example, some of them with incorrect drawings referred to NaCl using its molecular formula at the symbolic level. In contrast, those with partially-correct drawings drew at the sub-microscopic level but could not demonstrate the ions of salt and water compounds to be dispersed (see Figure 9). This finding reveals that the PPSTs cannot consider particle size and cannot comprehend the dissolution phenomenon. From

**Table 9** The results of the analysis of the PPSTs' responses to the fifth question

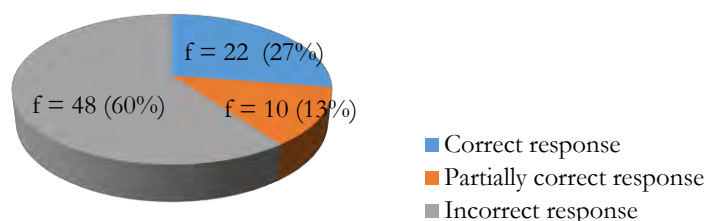
Representation Levels	Statements	Frequency values of the statements
Macroscopic	The saturated solution occurs.	19
	It becomes more concentrated. The amount of salt in the mixture increases.	18
	A blurry appearance occurs as salt dissolves in it. It becomes oversaturated.	17
	Salt gets more intense than water.	8
	Salt does not dissolve. It sinks to the bottom.	5
	The ratio of salt to water increases in the mixture. Dissolution time prolongs.	2
<b>Total</b>		69
Sub-microscopic	The distance between particles shrinks if the amount of salt in the mixture increases.	7
	Salt particles move closer to each other.	4
<b>Total</b>		11

**Table 10** The results of the analysis of the PPSTs' responses to question 6a

Representation Levels	Statements	Frequency values of the statements
Macroscopic	Salt does not filter through the paper filter. Instead, it is separated through filtering.	31
	The total amount of the solution filters through the paper filter. The salt has already dissolved in the water.	10
	Some amount of the salt does not filter through the paper filter. Instead, the dissolved part is filtered into the Erlenmeyer flask.	14
	The solution thoroughly filters through the paper filter, except for the substances that have not dissolved in the water.	22
<b>Total</b>		77
Sub-microscopic	The separated substances stay on the filter: Sodium and chloride.	3
<b>Total</b>		3

the result of analysis of the PPSTs' statements to the fifth question as to the chemical representation levels, we found that these statements were at macroscopic and sub-microscopic levels (see Table 9). Although the PPSTs had mostly incorrect drawings, their statements corresponded to the macroscopic and sub-microscopic levels. The macroscopic statements include scientifically correct responses expressing that saturated solution occurs ( $f = 19$ ) and a more concentrated solution is formed than the previous salt-water solution ( $f = 18$ ). Some PPSTs ( $f = 17$ ) were also observed to refer to a visible phenomenon where water blurs as salt dissolves in the water. This finding indicates that the PPSTs had statements matching with the

macroscopic level. To assess the statements in terms of scientific accuracy, despite being sub-microscopic responses, these statements show that the PPSTs misunderstood that the distance between salt particles shrinks to get closer to each other. Among the study results is also the inability of most of the prospective teachers to draw the saturated solution at the sub-microscopic level. The great difficulty is caused by their inability to consider how the ions in the solution would move. Many studies have shown that prospective teachers find it challenging to understand the representation of particles existing in solution (Adadan, 2014; Demirbaş et al., 2011; Valanides, 2000). However, the macroscopic statements of the

**Figure 10** PPSTs' responses to question 6a presented with their frequency and percentage distribution by categories

prospective teachers concerning the saturated salt-water solution coincide with scientific accuracy. So, this shows that they do not have problems with the visible dimensions of phenomenon or phenomena but with the invisible particle behaviors as seen in their statements and drawing. So mental modeling and a greater degree of interpretation are required to overcome the obstacles of this sub-microscopic level and understand the information conveyed in the representation (Head et al., 2017).

The next question (6a) that the PPSTs were asked: "What would you expect to happen if you pour the hot salt-water solution into a filter paper?". Figure 10 shows that more than half (60%) of them had incorrect answers, while those with correct answers accounted only for 27%, and partially-correct answers accounted for 13%. As question 6a has a sensate basis of observation, it is a question regarding the macroscopic level. The representation levels indicate that most PPSTs had macroscopic statements (see Table 10). From the macroscopic statements of the PPSTs, we concluded that they had many miscomprehensions. For example, they stated that salt separates from water through filtering ( $f = 26$ ), and the quantity of non-dissolved salt does not filter through the filter paper ( $f = 14$ ). This finding shows that the PPSTs could not explain filtering, which is one of the mixture separation methods. Despite the experiment and video demonstrated to facilitate comprehension of a chemistry subject, the prospective

teachers could not distinguish the mixtures from each other. Wang, Chi, Luo, Yanga, & Huang (2017) stated that to understand chemical processes such as filtering and crystallization, symbolic representations should be included in the learning process of learners and macroscopic representations.

In another question (6b) asked the PPSTs, they were instructed to draw how the particles formed in the flask and explain the reasons for their drawings. In Table 11, the results of the analysis of the PPSTs' drawings revealed that 62.5% of them had correct drawings, while 32.5% of them had incorrect drawings. Those with incorrect drawings illustrated the salt particles attached ( $f = 9$ ), solidified ( $f = 10$ ), or freeze ( $f = 7$ ) (see Figure 11). These findings demonstrate that they confuse crystallization with freezing, and they could be unable to think that the crystals forming in crystallization are separated from the solvent. The prospective teachers described the crystallization of salt particles as freezing and solidification, demonstrating that they confused crystallization with freezing, although they are two different phenomena. This situation reveals that the prospective teachers completed the science courses of primary and secondary schools where basic concepts are learned and the chemistry course of the grade-1 high school with inadequate and inaccurate knowledge. Nevertheless, many studies are emphasizing that science subjects should be taught effectively, especially in the learning process

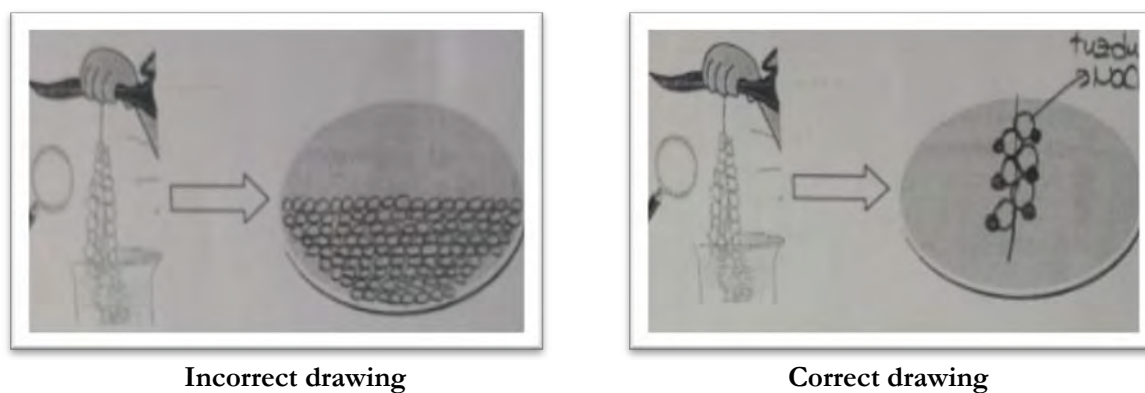
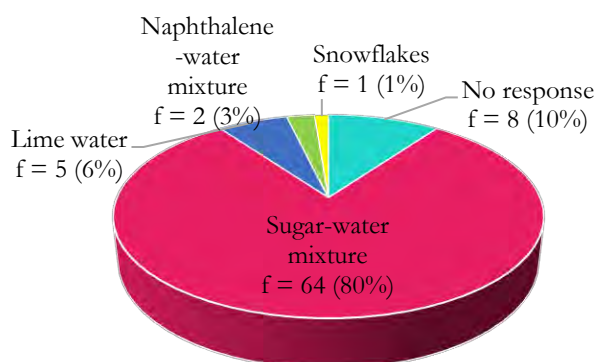


Figure 11 Examples of the graphs drawn by the PPSTs in response to question 6b

Table 11 The results of the analysis of the PPSTs' responses to the question 6b

Levels	f and % values	Statements	Frequency values of the statements
Correct drawing	50 (62.5%)	It is crystallized. Because salt particles are dissolving in water, move closer.	28
		The particles left on the string are salt crystals.	12
		The only salt remains as the water evaporates.	10
Incorrect drawing	26 (32.5%)	It is a solidified form.	10
		Salt particles are attached to each other.	9
		It is frozen.	7
N/A	4 (5%)		4
<b>Total</b>	<b>80 (100%)</b>		<b>80</b>



**Figure 12** PPSTs' responses to question 7 presented with their frequency and percentage distribution

extending from primary education to university, and therefore by providing transitions at macro, symbolic and sub-microscopic levels (Aydeniz et al., 2017; Derman & Ebenezer, 2020; Kelly et al., 2017; Tsaparlis et al., 2010).

The final seventh question investigated the other mixtures that the PPSTs might know can be separated through crystallization. Again, 80% of them responded, referring to sugar-water solution (see Figure 12).

When all the findings were considered, it was revealed that the PPSTs could not think in a triple structure (macroscopic, sub-microscopic, and symbolic) and could not combine them in related content of the crystallization experiment. As emphasized in the literature (Banawi et al., 2019; Derman & Ebenezer, 2020; Hermita et al., 2020) and found in this study, the understanding of prospective primary school teachers require to include macroscopic, sub-microscopic, and symbolic levels.

## CONCLUSION

The subject "Science" at the primary education contains specific and basic chemistry concepts such as homogeneous and heterogeneous mixtures, water and water solutions, dissolving, and crystallization (Januik & Mazur, 2010). Therefore, prospective teachers who are well trained in these subjects are needed in teaching to ensure quality science education. Our results herein revealed that the prospective teachers had inadequate knowledge about the relevant chemistry concepts. Moreover, the responses of the prospective teachers discovered the existing problems that they have in terms of chemical representations. The results also demonstrated that their responses were mainly at the macroscopic level, while they had great difficulty explaining at the sub-microscopic and symbolic representations levels. This result shows that the students of the prospective teachers may also have weak knowledge in their professional lives. It will lead to the fact that there are students who cannot respond to the invisible state of matter in daily life. They cannot perform meaningful learning because they cannot establish a

relationship between representations. Therefore, it is expected that prospective teachers who can understand the microscopic world and teach it by simplifying it will be trained (Nandiyanto et al., 2018). Additionally, the results of this study intensify the data of prospective primary school teachers' understanding of the crystallization experiment. Hence they become the inspiration to ensure quality science education and further research.

Many studies show that primary school students at the concrete operational stage have difficulty comprehending such concepts as chemical change, physical change, dissolution, heterogeneous mixture, and homogenous mixture unless they associate them with daily-life phenomena (Donovan & Bransford, 2005; Taşdemir & Demirbaş, 2010). For this reason, PPSTs should teach these concepts by using macroscopic statements and employing sub-microscopic drawings and representations that might appeal to students' concrete learning. Papageorgiou, Amariotakis, and Spiliotopoulou (2017) pointed out that chemical representations serve as a basis for the constructed internal representation and help students consolidate their understanding of an abstract concept. It is also expressed that employing various instructional technologies such as animations for these representations helps reinforce concrete learning of these concepts (Kelly & Jones, 2008; Pekdağ, 2010). In our study, the prospective teachers have displayed an animated video along with the demonstration experiment, which also served as a model in teaching these concepts.

The participants of the study have a remarkable impact on our results. Many studies in the literature report that prospective teachers have negative emotions rather than positive emotions when teaching topics related to physics or chemistry since the participants are prospective primary school teachers (Brigido, Bermejo, Conde, & Mellado, 2010). When the negative attitudes of prospective teachers are reflected upon concepts of physics or chemistry, their students might have difficulties in learning. Therefore, prospective teachers should get acquainted with physics

and chemistry concepts and learn the conceptual structures properly to develop a positive attitude towards teaching these concepts. Implementing science activities in primary education also poses an issue concerning science concepts. For this reason, more effective science training programs should be arranged to use science activities frequently and effectively (Papageorgiou, Kogianni, & Makris, 2007).

The present study allowed prospective teachers to explain chemical phenomena using their conceptual structures at different chemical representation levels, thereby allowing them to get curious about and interested in exploring chemistry. There have been some recommendations developed based on the results and the relevant literature:

- Hands-on science laboratory practices that incorporate different teaching techniques supporting primary school teachers and teaching basic chemistry concepts can be implemented in demonstration and as teamwork. Prospective teachers might therefore be allowed to get more experience on science concepts.

- Difficulties experienced at any level of chemical representation might affect comprehension of other representation levels; thus, determining their state of comprehension at all three levels is critically important to ensure efficient teaching of basic science concepts in chemistry. Therefore, teaching plans should be designed in a way attaching importance to these representation levels in teaching basic science concepts such as dissolution, solubility, and crystallization.

- PPSTs must attend a quality science teaching so primary school students, who will encounter the subjects and basic concepts of science for the first time, acquire accurate knowledge of the basic science subjects and concepts. To raise the quality of science teaching, the education curricula of prospective primary teachers must be revised and improved as needed.

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## NOTES

A part of this study is presented as an oral presentation at the 2<sup>nd</sup> International Congress on Seeking New Perspectives in Education.

## ABBREVIATIONS

PPSTs, Prospective Primary School Teachers; N/A, No answer.