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"Teach Your Classmates About the Behavior of Water with School-Level Science Models": An Experience in Initial Preschool Teacher Education

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Abstract Prospective preschool teachers (PPTs) need to have learning experiences with the practice of scientific modelling to be able to design appropriate lessons as teachers. In the literature on research in science education, scarce experiences of PPTs in scientific modelling can be found. This study aims to fill the knowledge gap about PPTs' representations of water and its states by means of models. To this end, an analysis is made of the models designed by PPTs and the difficulties they found in such a design process. The participants were 47 PPTs, working in groups of 2 or 3, forming 19 groups in total. The data source for analysis was the report written by each group. The oral presentation of these reports in class also served to clarify any doubts about the models elaborated by the PPTs. The models were analysed and categorized using qualitative content analysis methods, by combining inter- and intra-rater evaluation strategies. The results reveal that PPTs in general used a variety of resources to make models about the water molecule. Nonetheless, they found it harder to model the differences between the three aggregation states of water from a molecular perspective. The PPTs also acknowledged having had difficulties, such as when choosing and handling the materials they used to create the models or when thinking how to adapt them for the explanations to their peers. It is concluded with a discussion and implications of this study towards the PPTs' training in scientific modelling and its didactics.

Résumé Les futurs éducateurs au niveau préscolaire (FENP) doivent avoir des expériences d'apprentissage de la pratique de la modélisation scientifique pour pouvoir concevoir les bonnes leçons en tant qu'enseignants. La documentation portant sur la recherche dans le domaine de l'enseignement des sciences fait état de peu d'expériences des FENP en matière de modélisation scientifique. En se servant de modèles, cette étude vise à combler le manque de connaissances que nous avons au sujet des représentations de l'eau et de ses états des FENP. À cette fin, nous analysons les modèles conçus par les FENP et les difficultés rencontrées dans ce processus de conception. Les participants comprenaient 47 FENP, travaillant en groupes de deux ou trois, et formant 19 groupes au total. Le rapport rédigé par chaque groupe servait de source de données pour l'analyse. La présentation orale de ces rapports en

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classe a également permis de clarifier tout doute concernant les modèles conçus par les FENP. Nous avons analysé et classé les modèles à l'aide de méthodes d'analyse qualitative du contenu, en combinant des stratégies d'évaluation inter- et intraévaluateurs. Les résultats révèlent que les FENP ont plutôt utilisé une variété de ressources pour élaborer des modèles sur la molécule d'eau. Néanmoins, d'un point de vue moléculaire il a été plus difficile pour eux de modéliser les différences entre les trois états d'agrégation de l'eau. Les FENP ont également reconnu avoir rencontré des difficultés, notamment lors du choix et de la manipulation du matériel utilisé pour créer les modèles ou au moment de réfléchir à la manière de les adapter pour les expliquer à leurs pairs. Nous concluons l'article par une discussion et nous abordons les implications de cette étude sur la formation des FENP en ce qui a trait à la modélisation scientifique et à sa didactique.

Keywords Preservice teacher education · Scientific modelling · States of water · Water

Introduction

Modelling is a key scientific practice that should receive special attention in science education at all educational levels (Duschl et al., 2011; Gilbert et al., 2000; Harrison & Treagust, 2000). Nonetheless, this practice tends to receive little attention in basic-level science education, (Schwarz et al., 2009), despite the benefits it provides for the development of children's cognitive abilities (Åkerblom et al., 2019) mostly in 5- and 6-year-old children. Modelling can help them to make sense consciously of the natural world (Samarapungavan et al., 2015), and to develop incipient scientific arguments, hypotheses, and explanations (Harrison & Treagust, 2000). Children should therefore participate in activities that require both the construction and the analysis of elemental scientific models and learn to understand the purpose of those models in representing and explaining phenomena (Ravanis & Boilevin, 2022). This is recommended, for example, in the *Next Generation Science Standards* where it is suggested starting modelling in K-2 (5–8 year olds) by using and developing basic models such as diagrams, drawings, physical replications, dramatization, or storyboards that represent concrete events, such as patterns in the natural world (NGSS Lead States, 2013). Although less explicitly, the science curriculum for preschool education in Spain also encourages the use of basic scientific models when it states the representation of different phenomena that occur in the child's usual context (Ministry of Education, 2008).

Water is an ideal curricular content with which to initiate children in scientific modelling (Ahi, 2017; Bergnell, 2017; Kambouri-Danos et al., 2019; Ravanis et al., 2022) because it is a normal substance in lives, but also complex to understand (living beings need water, contamination, lack of water in some countries, diverse and special properties, etc.). Studying water can be engaging and attractive for children, and ideal to perform hands-on activities, involving the use of incipient scientific models to explain some behaviors of water. In addition, some studies have proved the feasibility of initiating children into abstract notions such as molecules (Åkerblom, et al., 2019), which is essential to explain many of the water behaviors. It hence is also of interest to address during the training of preservice preschool education teachers (henceforth, PPTs). If the PPTs have not themselves had learning experiences with the practice of scientific modelling in general, and in relation to water in particular, it will be hard for them to later design appropriate lessons that can be implemented in their classrooms when they are working as teachers (Baumfalk et al., 2019; Cruz-Guzmán et al., 2020a; Mosquera et al., 2018).

It is important to highlight the scarcity of works focused on the science education of PPTs (among others, Akerson, 2004; Barentien & Dunekacke, 2022; Garbett, 2003; Roth et al., 2013). The significance of the study lies in the improvement of the quality of the training of PPTs, who must go deeper than their students into the models they are going to handle as teachers to improve their knowledge of science content and associated scientific practices, in order to acquire sufficient mastery and confidence to then design their teaching proposals conveniently adapted (therefore, much simplified) to their teaching level. Previous research (Cruz-Guzmán et al., 2020a) looked at the effectiveness of a training plan to initiate PPTs in the practice of scientific modelling with water as the object of study. Once the PPTs had been instructed in this scientific practice, the next step was for them to design their own school-level scientific models. The aim of this study is therefore to present the results and conclusions of the analysis of these models in terms of their strengths and weaknesses, with a view to improving future teacher training actions in this regard.

Models and Scientific Modelling in Science Education

Scientific models can be defined as simplified representations of objects, phenomena, processes, ideas, or systems of physical reality which are created to explain and make predictions, as well as to communicate scientific ideas (Cruz-Guzmán et al., 2017; Acher et al., 2007; Gilbert et al., 2000; Nersessian, 2008; Oh & Oh, 2011). Teaching science through modelling involves the pupils' minds because it means the permanent modification and (re)construction of their own theories and models (Halloun, 2004; Nersessian, 2002; Oh & Oh, 2011). Acher et al. (2007) highlighted the manipulation of materials and social interaction as being among the main benefits of the practice of modelling in science education. Once the models have been represented by the students, they can be compared and discussed in class under the teacher's supervision. In this sense, modelling in science education requires bringing into play different resources or instruments (e.g., images, maquettes, simulations, and analogies) to develop and validate models. According to Gilbert (2004), this perspective suggests using models in different ways: (i) material or concrete (representation with 3D materials); (ii) verbal (oral or written description of the elements of the model and their relationships, of the metaphors or analogies on which it is based, etc.); (iii) visual (drawings, diagrams, animations, etc.); (iv) gestural (use of some parts or all of the body to make the representation); and (v) symbolic (symbols, formulas, equations, etc.).

Van Joolingen (2004) distinguishes three types of activities related to models: (i) *exploratory modelling*: with them, students discover properties of a model, change parameters, and observe changes that happen; (ii) *expressive modelling*: students make models to express their ideas about the represented system; and (iii) *inquiry modelling*: students (re-) construct a model from data, to explain results or to predict phenomena. Justi (2006) includes the procedures or components of modelling, as initial observations of the process, selection of the parts to be modeled, elaboration of an initial model and its representation, manipulation and experimentation, elaboration of a new model if it is necessary, and communication of limitations and characteristics of the final model.

Ashbrook (2020) and Forbes et al. (2015), among others, describe how teachers can use scientific modelling in their classes as a desirable methodology. They can assess their pupils' understandings and the parts that seem important to them, so they can discuss these models with them. These studies reveal that it is not only desirable but also possible to initiate preschool children in the use of models to understand natural phenomena (Ravanis et al., 2022). Therefore, this implies the need to train PPTs in the practice of scientific modelling.

Literature explain how modelling can help children to learn. Different authors (Louca & Zacharia, 2023; Plummer & Ricketts, 2023) assert that children engage in science practices to learn more about their world and help them become scientifically literate citizens. They claim that more research is needed to understand the range of ways preschool children can do science when supported with appropriate strategies and materials.

Models on Water Molecules in Preschool Education

Water is a topic widely addressed in the pre-primary education stage (Ampartzaki et al., 2021). Gelir (2022) asserts that children, from a young age, can learn about natural phenomena with a certain level of abstraction through activities directed by their teachers. Hence, attempts have been made in didactics research to develop resources that allow concepts and abstract ideas to be converted into (in Piagetian terms) concrete approximations, to make them assimilable at an early age (Öcal et al., 2021).

Åkerblom et al. (2019) studied the preschool children's conceptions of water molecules and chemistry before and after participating in a playfully dramatised early childhood education activity. They corroborated the learning of a group of children in the class about water at the microscopic level. Also, Kambouri-Danos et al. (2019) worked on the properties of water in the 5–6 year-old classroom. Specifically, they used experimental activities accompanied by predictions and conclusions to analyse the precursor models that children were able to construct when studying the phenomenon of water state changes. They observed that they constructed sufficient explanations of melting (64/91), evaporation (68/91), condensation (75/91), and freezing (82/91). They concluded the suitability for this stage of the construction of these precursor models, as intermediaries between mental representations of reality and school scientific knowledge, preparing their thinking and forming a basis for the later formation of more complex models. Ahi (2017) studied the school science models that 5–6-year-old children were able to construct about the water cycle before and after an instructional process. In the same vein, Levy (2013) addressed the construction of physical systems performed by 5–6-year-old children, to investigate the physical properties of water. She believes that the study contributes to the understanding that design- and construction-based learning environments for understanding scientific principles should be facilitated in early education.

Scientific Modelling in Preschool Education Teacher Training

Scarce experiences on the training of PPTs can be found in the literature on science education research, despite the importance of training future teachers at the initial levels of education. For example, Kenyon et al. (2011) analysed the modelling of PPTs about the movement of the water in the plants, through evaporation and condensation. PPTs were able to relate inquiry and modelling in their own teaching proposal designs, and to recognize that using evaporation and/or condensation as a focus helped the PPTs to construct, use, evaluate, and revise their models. The authors found that modelling phenomena related to different scientific content areas provide PPTs themselves better contextual examples of elements of modelling.

In addition, Saçkes and Trundle (2014) studied the learning of PPTs when they were asked to study the cause of moon phases through a psychomotor modelling activity. Participants used an exposed light bulb to represent the sun and styrofoam balls as a model for the moon to reproduce all the phases in the order in which they were observed. They also wrote and orally explained their understanding of the causes of moon phases. The authors concluded that the PPTs increased their interest in learning science concepts, as well as recognizing the usefulness of the conducted activity. PPTs engaged in conceptual change and constructed a scientific understanding of the cause of the lunar phases.

There are more experiences studying preservice elementary teachers' skills for modelling, which may be interesting to consider as well. For example, Lee and Jones (2018) studied modelling of the water cycle with preservice elementary teachers who selected aesthetically pleasing and simple in design models. They selected visual models more as a pedagogical tool to illustrate specific elements of the water cycle and less often as a tool to promote student learning related to complex systems. Couso and Garrido-Espeja (2017) also detected a general improvement in the preservice teachers' models by the end of the intervention about the particles of matter in the volume contraction of an alcohol-water mixture, highlighting that the material's macroscopic properties (density, temperature, etc.) were caused by the arrangement/interaction between the particles (their speed in vibrating, etc.).

Research Questions

Scarce experiences about early childhood teacher training in scientific modelling can be found in the literature of research in science education. These experiences allow students to practice newly developed skills by simulating a scenario where that skill may be required (Çiftçi & Topçu, 2022; Hidayati & Pardjono, 2018), providing a comprehensive learning experience for teacher education students. This work aims to fill the knowledge gap about PPTs' representations of water and its states. Accordingly, the aim of this study is to analyse the models designed by PPTs and the difficulties they came across designing them when they were asked to teach their peers about water behavior. The study was guided by the following questions, which link to the mentioned research gap:

(1) What models do PPTs design to represent the water molecule and the states of water?
(2) What difficulties do PPTs come across when designing their models?

Method

Participants

The participants were 47 PPTs (46 women and 1 man, between the ages of 22 and 40, and with a mean age of 24.7 years), who were selected because of accessibility at the time of the study (convenience sample). They were students of an optional subject of 4 months duration (6 credits) denoted "*Environment Exploration Workshop*," which corresponds to the last year of the Bachelor's Degree in Preschool Education at a Spanish university.

The PPTs worked in groups of 2 or 3, forming 19 groups altogether. With respect to the profile of the participants, it should be noted that the vast majority of them had a low predilection for science and its teaching. In general, they had a fairly limited science-related academic background. Only 12.5% of them had studied science in upper secondary education. Most had accessed the university degree course from itineraries related to social sciences or humanities (52.5%) or from professional training related to education (35%). Once they were in the course, they had to take 4 compulsory credits of basic instruction in a biology subject about human development, and a 6-credit subject about science teaching methods. These credits had been completed before the PPTs took the elective course in which this experience was developed. It is also appropriate to report that the syllabus of Preschool Education in our university does not include compulsory basic pure science disciplines, with scientific practices nor any physics or chemistry content. The optional subject attended by the participants is an exception to this lack of training in basic science. PPTs who choose it used to have high vocational levels.

The context in Spain, in terms of preschool education, is summarised in the latest regulations (Ministry of Education, 2022). The curriculum requires that children have to be taught the issues of an area called "Environmental Discovery and Exploration." These contents are, among others, exploration of objects and materials through the senses, identification of the qualities or attributes of objects and materials and effects produced by different actions on them, experimentation with natural elements, common natural phenomena: impact on your daily life, basic temporal notions: change and permanence, and so on. Spanish Education Bachelor's Degrees are required to teach trainee teachers about science and how to teach it.

Instructional Process

Before the PPTs designed their models, they had received explicit instruction about school-level scientific models using for this purpose water as school science content. Based on the idea of putting themselves in the teacher's shoes, teaching their peers (Çiftçi & Topçu, 2022), the PPTs were asked how they could represent the molecular structure of liquid water and the different states of water (Cruz-Guzmán et al., 2020a). Through an active learning–based teaching approach (Freeman et al., 2014), this instruction was carried out by the first author in five phases (5 sessions of 2 h each): (i) the PPTs responded individually to a questionnaire in order to diagnose the models they would create about the structure of water and its behavior; (ii) in a whole-class group session, the PPTs were introduced to basic notions about scientific modelling (purposes, types of models, functions, limitations, etc.) through a combination of direct instruction and small tasks of reflection and discussion for their assimilation; (iii) with the help of the instructor (orientations, scaffolding, and feedback), the PPTs organised themselves into groups to elaborate their own models to represent the water molecule and the states of water; (iv) in a whole-class group session, the PPTs shared with the rest of the class the models they had developed for their presentation and evaluation, and to implement lessons for improvement (reformulation of the initial models); and (v) the PPTs responded again individually to the initial questionnaire in order to assess whether there were progressions in the models imagined by the PPTs. In sum, the instructor's role during the teaching intervention was to guide the PPTs in thinking about their models, moderate the discussions among PPTs in the whole-class session, make clarifications, and raise additional questions to deepen and enrich the sharing as much as possible.

Once that first basic instruction has been carried out, for the PPTs to be able to elaborate models, the PPTs and the instructor held discussions in which the latter posed the question: "*We have just discussed in class what water is like 'inside' and what happens inside when ice freezes, evaporates, or melts. Now you need to train in developing models. In this case, imagine you have to teach your peers about the water molecule and what happens during the changes of state. What school-level science models would you design?*" The discussion required one more session (session 6).

The PPTs had at their disposal all kinds of stationery and everyday materials with which to make their models, such as balloons, pulses (dry beans, etc.), plasticine, balls of wool, and scissors. These materials were provided for them as part of the course. The PPTs required two additional sessions (sessions 7 and 8) with the instructor, as well as time outside class (approximately 4 or 5 h). The instructor maintained constant dialogue with the groups as they needed scaffolding to overcome the difficulties they were encountering, and to be able to advance towards the set purpose of developing models about water. The PPTs' models were not constrained by the use of particular materials.

Data Acquisition and Process of Analysis

The main source of data to respond to the first and second research questions was the report written up by each group about the school-level scientific models they had designed to teach about water and its changes of state. The analysis of students' productions in their reports of class work is reasonable and is common in research with similar purposes to this one (e.g., García-Carmona et al., 2017; Nivalainen et al., 2013) framed within a content analysis methodology (Mayring, 2000).

In addition, the oral presentation of these reports in class served to clarify any doubts about those models. The PPTs were requested to register in their reports the following information: (i) the school-level scientific models that they designed to teach their peers about the water molecule and the behavior of water molecules in ice, liquid water, and water vapour, detailing the process followed in their elaboration; and (ii) a detailed reflection on the difficulties they had encountered during the creation of the models, and how they tried to overcome them (from the beginning of the process until the moment when they presented their models in class to the other groups).

Data collection was separated from normal teaching because the report written by each group was not mandatory for passing the module, and the later report analysis for this work was much deeper than the assessment of the students in the context of the subject. However, due to the motivation of the PPTs, all of them who used to come to class handed in the report. In order to ask PPTs for permission to deeply analyse their reports for this work, an online activity was enabled, different from the one used for the subject assessment, in which the purpose of this work was explained in writing, so that if they agreed they could attach their report online on the subject platform. Given that this is an optional subject in the last year of the degree, the classroom atmosphere is very relaxed and the instructor-PPT relationship is very cordial and pleasant. Therefore, it cannot be said that there were any power relationships that could have influenced the results of this study.

Given the qualitative and interpretive nature of the study, the models developed by the PPTs were categorized by combining inter- and intra-rater evaluation methods. The intra-rater process was carried out by the first author to obtain a first complete categorization of the models proposed. This was an iterative and inductive process of interpreting and classifying information (Mayring, 2000). Nonetheless, given that the authors of this study had an extensive experience in the categorization of school-level scientific models, it only took two rounds to obtain the first complete categorization, even though some doubts around 10% of the PPTs' responses remained. After the first author had made this first categorization of all the models (intra-rater process), which was also revised and validated by the other two authors, the three ones discussed on those cases where the first author had doubts about the categorization.

As a result of this inter-rater process, a full agreement was finally achieved to the definitive categorization of all models proposed by the PPTs. The changes were related mostly to the formulation of the category. For example, there were two different categories with the labels "*They are unable to create any model about the behavior of the molecules in the different states of water (ice, liquid water, and water vapour)*" and "*They describe the observable characteristics of water in its different states of water*." They were merged into a single category labeled "*They fail to propose a molecular model for the states of water, or they only describe them at an observable level*." The result of all this was the definitive categorization of the models that the PPTs had developed. Similarly, in order to contribute to the objectivity of the analysis (Shenton, 2004), the "Results" section includes photographs of the PPTs' models and textual responses taken from their reports. Table 1 shows the relationship between the research questions and the data acquisition and analysis.

Results

Models to Represent the Water Molecule

The 19 groups proposed 27 different models to represent the water molecule, with some groups choosing more than one form of representation. All of them were "acceptable" models, as each one had three units, one oxygen and two hydrogens. The three units had a strong connection. Thus, 16 groups created different maquettes of the water molecule (Table 2), three groups chose a bodily representation, two groups created an illustrated story, another two performed a theatrical representation done by the teachers, one group recorded a video with molecules that they gave voice to, and another group made fancy dress costumes of molecules.

Table 1 Data sources and its analysis research questions

Research questions	Source of data	Data analysis
1. What models do PPTs design when they are asked to teach their peers about the water molecule and the states of water?	The school-level scientific models PPTs had designed (showed in the final reports and oral presentation): PPTs' representation of water molecule PPTs' description of the behavior of water molecules in ice, liquid water, and water vapour	The models were categorized by combining inter- and intra-rater evaluation methods
2. What difficulties do PPTs come across when designing their models?	Final report: PPTs' answers to the question: "What difficulties had you encountered during the creation of the models, and how did you try to overcome them?" PPTs' identification of difficulties	The report revealed difficulties that were categorized by combining inter- and intra-rater evaluation methods. Instructor identification ones are discussed along the study

Table 2 Modelling to represent the water molecule

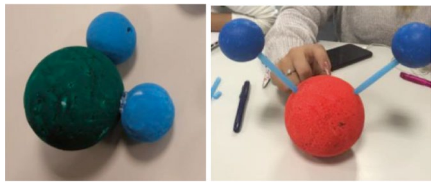
Resource used	Descriptor	Number[1]
1) Maquettes with:		16/19
- Coloured polystyrene balls and toothpicks or straws		5/19
- Plasticine balls, assembled with toothpicks, plasticine joints, or directly		4/19
- Felt fabric balls or faces, held together using toothpicks or fabric links	"The mother represents the oxygen in the water, and she has two children (hydrogens). The mother loves her children very much and it is impossible for these dolls to come off (strong union)." 	2/19
- Wool pompoms and wooden sticks		2/19
- Balloons	(i) With inflated balloons that are linked by the nozzles; (ii) Blue balloons filled with rice and red ones filled with less rice. Atoms are linked with toothpicks. 	2/19
- Other elements	Chickpea oxygen, stuck to two lentils with putty	1/19

Table 2 (continued)

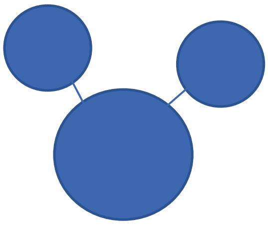
2) Dramatization by the participants (classmates)	(i) The head is oxygen (O), and the hands are hydrogen (H); (ii) Each person is an 'O' or an 'H' (depending on hat colour). They link their arms to form a water molecule; (iii) When the music stops, the participants link up together. Some are atoms of 'O' (dressed in blue) and others of 'H' (dressed in red). They are linked at their arms with rubber bands so that they cannot come loose.  	3/19
3) Drawings	 	2/19
4) Illustrated story	i) The molecule is a cat with little ears; (ii) Once upon a time, there was a water molecule called Moly. Her body was like a big head with two little ears. So, she had a large blue ball (called oxygen instead of head) and two smaller red balls (called hydrogens instead of ears). 	2/19

Table 2 (continued)

5) Dramatization by the teachers	Atoms are attached to each other by the arms.  	2/19
6) Video	Video with talking paper figures (straws linking atoms). 	1/19
7) Costume		1/19

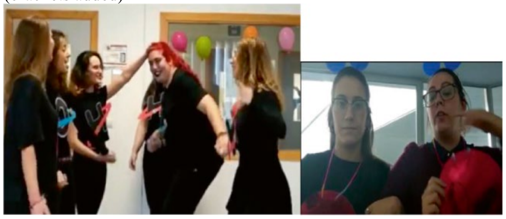
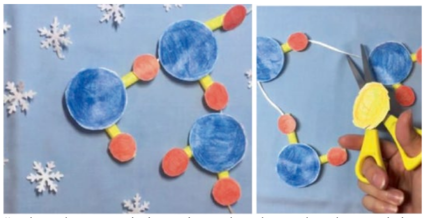
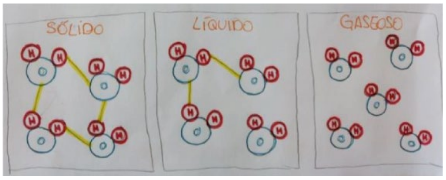
[1] Number of groups that make external representation. The same group can make more than one type of representation to model the water molecule.

Models of the Behavior of the Molecules in the Different States of Water

Only 10/19 groups finally managed to develop some type of model to represent the states of water at molecular level. Table 3 presents the different levels of formulation of the models proposed. The other nine groups either were unable to design a model to represent the differences between the states of water or did not do so at a molecular level, i.e., they limited themselves to describing the changes that are observed experimentally in water when, as the temperature gradually rises, it changes state (Level I).

Of the groups who did design models about the changes of state of water (10/19 groups), two were at an intermediate level of formulation (Level II). Their models were characterized by representing the changes of state in accordance with the different distances between the molecules. So that in the solid state they were "more together" than in the liquid state, and completely "isolated" in the gaseous state.

Table 3 Modelling to represent the water states

Formulation level	Descriptor	Number
I. They are unable to propose a molecular model for the states of water, or only describe them at an observable level.	"For this, we bring an ice cube (...) We subject it to heat and let the pupils observe the transformation (...) what is in the container is liquid water (...) More heat is exerted again, and we invite them to observe the vapour that emanates from the container."	9/19
II. Changes of state are explained in terms of intermolecular distances	"When solid [the molecules] are all (...) very close together (as if they were 'cold'), similarly for liquid, but with the bonds further apart, and for gas, the molecules are not bonded" (brackets added) 	2/19
III.a. The changes of state are explained in terms of the mobility of the molecules	"In ice, all the molecules are very still and bound together due to the 'cold' they feel. In liquid water they can move, some go to play with their friends (like Moly), other molecules are alone, they go their own way. In water vapour: everyone, even Moly, wants to be alone..." 	3/19
III.b. The changes of state (solid → liquid → gas) are explained in terms of the gradual breakdown of intermolecular unions due to the increase in temperature	 "When the water is in an ice cube, the molecules are joined together, when the water is liquid, some molecules are joined together, and others are separated, but when the water is in a gaseous state, all the molecules are separated." 	5/19

At Level III of formulation, eight groups constructed a desirable model that represented the changes of state through the gradual breaking of the unions between the water molecules as the temperature rises. Thus, three groups differentiated the states (theatrically or through stories) according to the movement of the molecules, from the immobility of the solid state to the total freedom of movement in the gaseous state. The other five groups represented the changes of state, from solid to liquid to gas, with the gradual breaking of unions between molecules.

Table 4 Frequency of the difficulties the participants recognized

Difficulties	Number	Excerpts of representative responses
1) Choice of suitable materials or construction of the maquette	7/19	"The first difficulty arose when designing the model (…), we wanted to make it with manipulable materials (…), we already thought of pompoms: the pupils could make them, the materials were simple and easy to acquire, and they could be easily manipulated." "Another difficulty was when sewing our water molecule because, when we sewed the hydrogen bonds, we sewed them out of line, so we had to undo them and re-sew them correctly."
2) Carrying out an adequate didactic transposition for teaching their peers	6/19	"(…) It was difficult for us to use the model to transfer the scientific explanation so that everything made sense and was easily understandable (…). Nonetheless, when we thought about using cardboard, we could see that we had managed to get the maquette and the explanations to fit together in a logical and understandable way."
3) Choice of activity to model some particular contents	4/19	"… when we were able to think about different activities, we observed that something was missing in all of them"; "(…) we thought about making a video (…), but when we wanted to think about the union with other molecules, this idea did not fit, so we decided to change it and came up with the current idea."
4) Design of the story to teach with	3/19	"We managed to make the story with the help of the instructor and after several attempts."
5) Do not declare any difficulties	2/19	
6) Technical production of the audio-visual model	1/19	"Our classroom did not have the adequate dimensions, so we had to resort to a classroom of our companions, since it was larger. The green background was too small for the chroma, and we couldn't all be in the same sequence. Since we did not know about the Camtasia application for video editing, we had to watch several tutorials (…)."

Difficulties Manifested by the Preservice Teachers in Creating the Models

The difficulties detected and solved by the first author while the process was being developed have been described above. In addition, the PPTs acknowledged in their reports that they had had difficulties in creating their representations about the changes of state of water (Table 4). The number of difficulties presented is greater than the number of groups participating because any one group could present more than one difficulty.

The commonest (7/19 groups) was the construction of the maquette. In some cases, the choice of the materials needed went through different phases when the first ones they used gave problems, such as not obtaining the expected results (for example, because the bonds between the atoms were not angularly arranged or separated easily, while the bonds between the molecules needed to be manipulatable), or because they broke easily (e.g., the wool did not stay fixed onto the balls, the balloons that were filled with lentils lost them when they were joined with toothpicks). In all cases, the solution involved a change of material, for both the elements of the maquette and its bonds, until the final design was obtained. Overall, it was not a difficult obstacle to overcome, but it did require some time.

The second commonest difficulty (6/19 groups) had to do with the process itself of didactic transposition that the PPTs had to carry out. They recognized the difficulties they had in explaining to their classmates the models they had just built, sometimes assuming they lacked knowledge and interest to be able to do this. A smaller proportion of groups (4/19) stated that another difficulty they had to overcome was the choice of the type of model to create (videos, stories, maquettes, dramatizations, etc.), since each has its advantages and disadvantages. So they dedicated time to analysing which, among the different options, had the best characteristics. They tried to design models that allowed some manipulation, had internal coherence, entertained, and allowed for play and understanding of the concepts.

The 3/19 groups who chose the story as a model needed a lot of help from the instructor. Their initial drafts often were presented in language well suited, conveyed values, told understandable stories, and might even be accompanied by colourful and eye-catching illustrations. But the stories made no analogy in water molecule characteristics. The instructor proposed didactic modifications. For example, in their initial draft, one group began by describing the molecule as: "*Once upon a time, there was a water molecule called Moly. She was a big ball, she lived in Aqualand with her family and she had many friends*." The instructor, in addition to advising that a more detailed description of the molecule could be given, expressed the need to introduce the concept of the existence of millions of molecules within the liquid water that we observe.

This suggestion of the instructor was taken into account in the story as follows: "*Aqualand was a magical place, from the outside people only saw water, but really many molecules such as Moly lived within it*." The case was somewhat similar when dealing with the states of water since the listener would not have been able to deduce from the story the behavior of the molecules in the different states. For example, one story said: "*… she had superpowers, because when she played with many friends, her state changed to solid, she could become an ice cube! But when she went out with her 3 cousins, something very different happened to her: she became liquid*." After the instructor's corrections, the final version contained the following paragraph: "*When it was very cold, and people went out with scarves and coats, Aqualand became an icy lake, it was pure ice. In reality, what was happening inside was that Moly and her friends were all very close and still, because of how cold they felt…*." Finally, it should be noted that two groups did not report having had any difficulties, or that these were technical due to the handling of audio-visual resources.

Discussion and Conclusions

In order to answer the first research question (What models do PPTs design to represent the water molecule and the states of water?), the analysis of results made it possible to verify that the majority of

PPTs achieved to elaborate some representations to teach their classmates about the behavior of water when changing state. This is key if the core aim was to familiarize them with the scientific modelling; especially as they had no previous experience with this scientific practice. In this sense, it can be said that the educational experience in general had a positive effect in involving and training the PPTs in scientific modelling. However, this study reveals both strengths and weaknesses in PPTs when performing the modelling practice to explain the aggregated states of water.

With respect to the strengths, it should be noted that all 19 PPT groups designed acceptable models to represent the water molecule. Likewise, of the 19 participating groups, 10 were able to develop models that allow participants to imagine the behavior of molecules in the different states of water and thus justify what is observed at a macroscopic level. Of these, 8/19 groups designed models that really made it possible to represent the states of water at molecular level in a desirable way that is in accordance with the school-level scientific model (the higher the temperature, the more mobile the molecules and the greater the breakage of the unions between the molecules). This result is in line with what has been set out by other authors in preschool education, such as Åkerblom et al. (2019). In addition, PPTs' creativity was manifest in their use of a multitude of materials and resources to design models about the water molecule, including plasticine, wool, balloons, theatre, dance, and children's stories. This is in syntony with the results of Cruz-Guzmán et al. (2020b) who verified PPTs' inventiveness and originality in designing "science corners" with activities that promote inquiry, model construction, manipulation of materials, classification games, etc.

In relation to the second research question (What difficulties do PPTs come across when designing their models?), not all the groups were able to finally propose a model representing the states of water at microscopic level. Sometimes their models only allowed the states to be described in their perceptible characterization (difference between ice, liquid water, and water vapour). And this was despite their having previously received scientific instruction in this regard (Cruz-Guzmán et al., 2020a). One of the reasons may be that they themselves did not understand the phenomenon well at a molecular scale. The scientific competence of the PPTs is in general fairly limited, since most do not come from academic backgrounds related to science (Cruz-Guzmán et al., 2020a, b). Perhaps this justifies even more the need for PPTs' initial training to include experiences in which they can carry out scientific models of this type of content (Åkerblom et al., 2019; Kambouri-Danos et al., 2019; Öcal et al., 2021). Among the groups that managed to design models about the states of water at molecular level (10/19 groups), two of them used the changes in the length of the molecular distances (the molecules coming closer or moving farther away) to express the differences between states at molecular level.

In addition to the aforementioned difficulties, which were deduced from the models the PPTs designed, when asked, they themselves explicitly recognized certain obstacles and difficulties they encountered while creating their designs. It is worth noting that being aware of these difficulties is an important value for the teacher training experience they had carried out, since the metacognition it promoted helped them develop meaningful learning, thus uniting cognitive psychology with science education (Campanario, 2000; García-Carmona, 2012). The most frequent difficulties were related to the choice of materials and the process of constructing the model itself. In all cases, these difficulties would be easy to overcome if the PPTs had more time to do so. In addition, the PPTs recognized the obstacles they encountered in making understandable the phenomena with their models, which had a certain scientific level of abstraction. In any way, this reflected their limitations in understanding school-level science content such as that dealt with in the study. Kenyon et al. (2011) also note that it can be difficult for novice preschool teachers to teach about evaporation and condensation processes through modelling, since these are concepts that require them to revise their own school-level scientific models. This is something that has been also dealt with in a previous study with these same PPTs (Cruz-Guzmán et al., 2020a).

Another difficulty highlighted by the PPTs was the choice of model. They became aware of some of the main characteristics of scientific models, such as *multiplicity and limited* (Oh & Oh, 2011), as they could see how there can be different models to explain the same phenomena and that a unique perfect model to explain the whole phenomena was not possible.

Finally, several groups were aware of the difficulty in designing a story to use as a model of the behavior of water molecules. The difficulties arose when they had to integrate scientific ideas into the story. Despite this difficulty, which they only overcame with the help of the instructor, the groups did not give up choosing to try to create a story. Like Orellana and Espinet (2009), they valued it as a resource facilitating modelling for teaching science in preschool education. Therefore, it is necessary to guide PPTs so that they do not lose sight of the story's didactic purpose. Among other stories, Christidou et al. (2009) also valued one ("the little magnet") about an adventurous hero who interacts with different materials/friends for work in class on magnetism.

Limitations and Implications for Future Research

In addition to the above, it is necessary to refer to the limitations of this study and the implications deriving from it. Among the limitations is the number of participants. At the time of the study, the authors only had access to a single group-class of PPTs (convenience sample), so that the sample was not large. In addition, they all belonged to the same educational context (the Faculty of Education Sciences of a university in Spain). Nonetheless, the information provided about the profile of the participants and the instruction designed, and the detailed description of the results and conclusions may constitute a good referent which can be applied, or taken into account, in other teacher training contexts with similar characteristics.

Another limitation is related to the fact that the model designs were limited to a specific school-level science content: water and its states of water. There remains the question as to how PPTs would handle this practice when designing models to teach other school-level science curriculum contents at that same educational stage. The results suggest that it is necessary to address scientific practices such as modelling in PPTs' training (Cantó et al., 2016; Mosquera et al., 2018) so that they can become familiar with them, and consequently feel encouraged to implement them with their future pupils. Likewise, it is necessary for the PPTs to carry out school-level scientific models because this process itself will help them understand what it really means to promote modelling in preschool education, assessing its possibilities and its difficulties. This study contributes to exemplifying that this challenge is viable, although not straightforward, and some of the arising difficulties have been characterized.

It is necessary therefore to set out future lines of work that allow the exploration and improvement of the initial training of PPTs regarding the practice of modelling. With this objective, and following the overall conclusions set out in this study, various future research proposals present themselves:

(i) To search for processes or experiences that help to overcome the difficulties PPTs have when designing models to teach about water in preschool education (such as making certain didactic transpositions or designing didactic stories to work on content at a certain level of abstraction, characterising the requirements that stories must have so that they help to acquire knowledge).

MacDonald et al. (2021) claim that existing research suggests that many educators experience uncertainty, or even fear, when it comes to teaching STEM content. Inquiry-based learning appears to provide a comfortable entry point for STEM for early childhood educators.

(ii) To study the PPTs' difficulties when they design models depends on the particular type of content of the preschool education curriculum; Kolby Noble (2016) suggests that more research is necessary to better understand the discrepancy between science background knowledge and confidence.

(iii) It should be highlighted that this work analyses the PPTs' group representations. Future research could be made with PPTs to study if their individual pathways would be different or not. Lin (2013) found there was no significant difference in related catheterization skill performance when comparing the effect of technology-based cooperative learning with technology-based individual learning in nursing students. However, the remaining variables differed greatly between the two groups.

(iv) To analyse how the models designed by PPTs work with preschool children. The latter is particularly important because it is true that it is not the same to imagine/design models to explain about the phenomena treated to classmates, future teachers, than to children. Therefore, an important next step will be to address in the preparation of PPTs the design of school-level models to explain to children the content of the preschool curriculum. Louca and Zacharia (2023) studied child-developed models (artefact analysis) and their oral presentations (discourse analysis) about the solution of substances in water, seeking to provide rich, detailed descriptions of the characteristics of these models. Plummer and Ricketts (2023) consider that children engage in two types of modelling practices: thinking about models and thinking with models, when they understand that images, drawings, or physical objects can stand in for the actual objects that they represent, so they apply models to help them make sense of science phenomena.

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Data Availability The data that support the findings of this study are available on request from the corresponding author [mcruzguzman@us.es].

Declarations

Ethical Approval This study met the ethics requirements for research that involves human subjects at the time the data was collected.

Conflict of Interest The authors declare no competing interests.

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