# Revision and Manipulation of Physical Models as Tools for Developing the Aquifer Model by Preservice Elementary Teachers

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**ABSTRACT**

Citizens show misunderstandigs about groundwater that hinder making informed decisions about problems such as the deterioration of aquifers and clean water supply. Science education should address this, including modelling practices about the aquifer model, along with a representation of the model, for example, as a physical model. Physical models have been extensively used in geology teaching, but students rarely construct, evaluate or manipulate them. This study addressed how the revision and manipulation of physical models contributed to the construction of a complete aquifer model by 80 Preservice Elementary Teachers (PETs) of two cohorts (subsequent years) that participated in a modelling teaching sequence that included fieldwork and the construction of a physical model. The model representations (drawings, writings, oral expressions, physical models) were analysed, based on Components-Mechanisms-Phenomena systems thinking framework, through a constant comparison method. Results show that, although PETs improved their models both years, it was in Year 2 when they improved the Phenomena dimension. PETs that constructed a complete model tripled those of Year 1. The conversations in groups and the model representations throughout the sequence show that the evaluation of the physical model when comparing it with reality during the field trip, and the manipulation of the physical models guided by teachers´ scaffoldings to encourage PETs to make representations and predictions, led them to revise and improve their models in Year 2. Therefore, we conclude that it is indeed the manipulation and revision of physical models that provides opportunities for revising the aquifer model and improving it.

Keywords: earth science education; models & modelling; multiple representations

## Introduction

Science education aims to develop critical citizens who make informed decisions about the problems they face. In fact, the competence 'Using scientific knowledge for decision-making and action' will be added to the existing science competencies in the PISA assessment programme in 2024 (Organisation for Economic Co-operation and Development [OECD], 2020). One of the problems of concern to society is the global water crisis, as it is estimated that two thirds of the world's population face water scarcity (Mekonnen & Hoekstra, 2016) and about 80% live in water-insecure conditions (Vörösmary et al., 2010). Most of the accessible freshwater is found underground (Intergovernmental Panel on Climate Change [IPCC], 2021), but groundwater is one of the most unknown components of the water cycle (Pan & Liu, 2018). Problems such as groundwater depletion or seawater intrusion are real global concerns (IPCC, 2021). Understanding these threats requires a minimum knowledge of groundwater. In fact, as several studies (Ben-Zvi Assaraf & Orion, 2005a) indicate, the less knowledgeable people are about groundwater and groundwater dynamics, the less aware they are of human impact on groundwater.

There are many obstacles to overcome in developing knowledge about groundwater (Arhurs & Elwonger, 2018). These include the high level of abstraction and the need to understand groundwater as a system in which the elements are both interconnected and interdependent. To overcome these difficulties, hydrogeologists often work with models, which help them to explain and predict groundwater behaviour. Models can be defined as representations of reality used for explaining and predicting scientific phenomena (Gilbert et al., 2000). Models are related to reality, to evidence, but also to theory: they reduce theory to concrete events (Sensevy et al., 2008), which is essential to make the abstract idea clear. Thus, scientists move from the abstract theory to the model and from this to the particular event, and in the opposite direction, from the particular reality to the model and to the general theory (Sensevy et al., 2008). In fact, modelling is one of the practices that scientists develop in their endeavour to understand the natural phenomena, that is, while they investigate the world, develop explanations and evaluate those explanations using evidence (National Research Council [NRC], 2012; Osborne, 2014). Science education experts advocate the incorporation of these scientific practices and authentic activities in the classroom (Jiménez-Aleixandre & Crujeiras, 2017; NRC, 2012) as a means of enculturating students in science (Brown et al., 1989).

Modelling can be defined as the construction, use, evaluation and revision of scientific models (Schwarz et al., 2009). The representation of the models in the modelling process can be effected by several modes, for example, by physical models, the use of which has been highlighted in various educational research projects (e.g. Miller & Kastens, 2018).

The incorporation of scientific practices in the classroom depends to a large extent on teachers (Bybee, 2014). A change in science teaching that aims to incorporate science practices requires changes in teacher training in order to improve teachers' knowledge of what science practices consist of and what strategies to use with their students (Osborne, 2014). In that sense, 'beginning teachers need to experience what it means to learn science concepts deeply and conceptually in ways that are consistent with how they will eventually be asked to teach' (Zembal-Saul, 2009, p. 696). Indeed, as Windschitl (2003) found when analysing the implementation of inquiry activities by trainee secondary school teachers, the key factor was that they had carried out these activities themselves, for example, in their initial training. However, teachers seldom have experienced learning activities that implied the development of scientific practices, similar to the ones they are supposed to carry in their classes. Indeed, Vo et al. (2019) found difficulties for teachers when carrying scientific practices, and highlighted the need for studies on primary school teachers' difficulties in modelling and promoting modelling. In a three-year longitudinal study, they followed four primary school teachers. They found that the teachers offered few opportunities to evaluate models compared to opportunities to use them, and that this corresponded to their conception of modelling. Their conception and practice changed as a result of the training they received, although, even in year three, they still showed shortcomings, such as a lack of consideration of the role of evidence. Engaging teachers in the construction, use, evaluation and revision of models is key for them to develop more authentic modelling processes.

In the practice of geology, the use of models, alongside fieldwork, is particularly relevant (King, 2016; Oh, 2019). Taken that geology is a historical and interpretive science that deals with phenomena from the past, Oh (2019) proposed a scheme of modelling-based abductive reasoning for geology in which models (representations of natural phenomena) can play the role of a resource to help the reasoner think. In his study drawings and gestures were the modes of representation. Donaldson et al. (2020) found that the explanation of structures and processes with gestures, and the creation of small-scale physical replications of an external environment are important constituents for enculturation in geology. That said, it is true that all geological phenomena (including groundwater) can only be understood in context. Field trips are thus authentic contexts for the enculturation of students (Donaldson et al., 2020; Petcovic & Stokes, 2014), and information gathered there must be used in the construction of geological physical models (Miller & Kastens, 2018). However, with respect to the teaching of geology, although 3D models are present in the classroom, there are few experiences in which students are involved in their construction and in the representation of processes. Teachers need to create contexts for students to exploit the potential of the physical models (Kastens & Rivet, 2010). Miller and Kastens (2018) observed that, while the teachers that participated in their research initially used physical models in their classes for expository and demonstrative purposes, after participating in a training programme, they went on to use them to engage students in using them as problem-solving tools.

The main objective of this work is to address how the revision of the model throughout the modelling process helps Preservice Elementary Teachers (PETs) to build an adequate aquifer model. Specifically, how the construction of the physical model, its evaluation based on the reality observed in the field, and its use and manipulation, assists in the model revision and development.

## The aquifer model

Models have been defined as partial representations of reality that try to explain and predict scientific phenomena (Gilbert et al., 2000), or as epistemic artifacts whose purposes are related to a multitude of scientific practices (Gilbert & Justi, 2016). In the literature, the term ‘model’ is sometimes used as a synonym for the representation or expression of the model, for example, as a synonym for the physical model. In this work, the term ‘model’ refers to the school scientific aquifer model. Note that when referring to a representation of the model, for example, through a physical model, this is specified.

The process of construction, use, evaluation and revision of scientific models is called modelling (Schwarz et al., 2009). In science education, this scientific practice is adapted to the conditions and educational needs of the students. This requires a didactic transposition of the scientific models and the modelling process. The idea of didactic transposition makes explicit that there is an inevitable distance between the scientific knowledge and its practices, and the knowledge and practices included in oficial curricula and classrooms (Tiberghien & Sensevy, 2015). As science education learning objectives are different from the research objectives of the scientific community, contents and their sequencing will be adapted to the educational context. Therefore, it is not possible to accurately reproduce the scientists' modelling process in the classroom. As Tiberghien and Sensevy (2015) point out, 'the authenticity can only be partial' (p. 1085). In this case, the didactic transposition of the scientific models has been done through the School Science Models (SSM) (Izquierdo-Aymerich & Adúriz-Bravo, 2003).

Bach and Márquez (2017) defined a school model of geological change based on systems thinking. Systems thinking has been applied to different systems, including biological and geological systems, it attempts to consider both the components and the connections/interactions between those components that make a system distinct and more complex than the sum of its parts. Characterising the parts of the system has been the subject of the work of, for example, Hmelo-Silver and Pfeffer (2004). They proposed the SBF (Structure-Behaviour-Function) conceptual representation, which they then modified (Hmelo-Silver et al., 2017) to the CMP (Components-Mechanisms-Phenomena) conceptual representation. This was designed to support learners in: framing systems thinking around a particular phenomenon (P); exploring the parts or components (C) of the system, and the interactions among those components through processes or mechanisms (M) that may result in the (P). The CMP representation was applied to the systemic view of the human body (Snapir et al., 2017), and is reflected in Bach and Márquez's (2017) proposal for the school geological change model.

Several works (Batzri et al., 2015; Ben-Zvi Assaraf & Orion, 2005b) focused on promoting and analysing students' systems thinking when dealing with geological systems and considered that high level performance was determined by making connections between the parts. As Ben-Zvi Assaraf and Orion (2005b) found, expert students were better able to focus on system behaviours, processes and functionality than novices, who were limited to pointing out structural components.

In the case of the aquifer model, Components refer to all the parts of the subsystems involved (geosphere, hydrosphere, atmosphere, biosphere), Mechanisms, as said, refer to all the processes and interactions between Components, for example: weathering, water flows, and changes in the state of water. The resulting Phenomena consists mainly of the formation of the aquifer and the river, and the changes that water table and water chemistry may experience.

Previous studies found that students face many difficulties in all dimensions of the model. Researchers agree that students often forget groundwater when depicting it: Ben-zvi Assaraf and Orion (2005a) analysed drawings of the hydrosphere by 177 secondary school students, and 70% did not identify groundwater as part of the water cycle. Forbes et al. (2015) and Pan and Liu (2018) also highlight the fact that students direct their attention to the hydrological and atmospheric components of the water cycle to a greater extent than to the elements of the geosphere.

Among the students who do identify water in the subsurface, the majority indicate that water flows through caves or 'underground rivers and lakes', similar to the way surface water does (Dickerson & Dawkins 2004; Pan & Liu, 2018; Sadler et al., 2016; Unterbruner et al. 2016). This misconception is directly related to the students' conception of 'solid rock' (Arthurs & Elwonger, 2018), which prevents them from understanding that these can have pores and therefore contain water inside (Arthurs &

Elwonger, 2018; Unterbruner et al., 2016). As Sadler et al. (2016) point out, students can easily appreciate that water is stored underground, but have many doubts about the processes and structures influencing groundwater storage.

Another recurrent error in students' representations is the isolation of groundwater: it is common for students not to draw connections between surface water and groundwater, demonstrating that they do not really understand these water bodies as part of a system (Pan &Liu, 2018); sometimes, they even draw isolated and static water bodies in the subsurface (Ben-zvi Assaraf & Orion, 2005a).

## Physical models as mediators for modelling

The representation of the model is one of the stages of the modelling process (Gilbert & Justi, 2016; Schwarz et al., 2009). It is intentional, and the intention can be communicative, cognitive or operational, and can be made by five modes according to Gilbert (2005): concrete or material (e.g. a plaster representation of a section through geological strata), verbal (spoken or written description of the entities and the relationships between them in a representation), symbolic (e.g. chemical symbols and formula, equations), visual (diagrams, graphs, virtual models), and gestural (body movement, embodiment).

Material 3D physical models constructed by students have demonstrated their potential as mediators for the modelling process in at least three dimensions (Gómez et al., 2007): between the students' initial ideas and the phenomenon, between the students' starting models and the teachers' models, and between the different levels of the students' model in the process. In their research, 11-year-old students, who were trying to construct the model of a living being, collectively made a physical model of a forest in which they later simulated a fire. The students were expressing their mental models while manipulating it, gesturing and talking around it (Gómez et al., 2007), which allowed the teacher to intervene, ask questions and help in the evolution of the children's ideas. Along the same lines, Bahamonde and Gómez (2016) highlighted the effectiveness of building physical models of the human body to model human digestion, and García and Mateos (2018) concluded that students who had built a physical model developed their ability to visualise human anatomy more than those who had visualised images.

Analogical reasoning through the use of physical models is arguably especially relevant in geology (Miller & Kastens, 2018; Torres & Vasconcelos, 2016), and particularly in hydrogeology (Dickerson et al., 2007), as it is a discipline that deals with processes that are difficult to observe. Three-dimensional representations should help students in reasoning spatially about the topic (Dickerson et al., 2007), establishing relationships between system components and representing unobservable mechanisms, such as permeability, in an observable way (Forbes et al., 2015).

Despite this potential, most of the time that physical models are used in teaching, especially in geology, they are not constructed by the students as expressions of their models, but are rather physical models that the teacher shows in an expository manner (Gray et al., 2011; Torres & Vasconcelos, 2016). As Gray et al. (2011) found, there is little documented experience of students building physical models to test their hypotheses. Kastens and Rivet (2010) evaluated how two physical models widely used in geology teaching represented real phenomena (attributes and relationships). They emphasised that beyond the attributes of the physical models, it is important for teachers to create contexts in which students can manipulate them, engage in discussion, ask questions, construct arguments, and so on. In this regard, the work of Miller and

Kastens (2018) addressed this problem through a programme for teachers, training them to strengthen and deepen the connections between physical dynamic models and their real-world referents, to answer questions about the real world using physical models, and to use physical models to interpret data from the real Earth.

## Objectives

This study focuses on how the revision of the model throughout the modelling process helps PETs to build an adequate aquifer model. In this context we analyse how the revision and manipulation of the physical model assists in the model revision and development. The research questions of this work are:

RQ1. How did the PETs who participated in a sequence of activities develop the aquifer model?

RQ2. How did the changes in the modelling process introduced in Year 2, specifically the scaffoldings for PETs to revise and manipulate their physical models, facilitate the development of the aquifer model?

## Methods

This section describes the sequence designed and the methodological aspects of the analysis. The research can be characterized as clinical education research (Bulterman-Bos, 2008) and was mainly based on the interpretative analysis (Erickson, 1989) of qualitative data (conversations between PETs).

### *Contextualisation of the sequence and the participants*

The sequence was carried out during the first term of the academic years 2018/19 (Year 1) and 2019/20 (Year 2). The participants were 41 and 39 PETs respectively, with an average age of 22 and working on the subject ‘New trends in Science Didactics’ of the 4th year of the Primary Education Degree. The second author was the teacher. PETs worked in groups of 3-5 people (9 groups in Year 1 and 8 in Year 2) and spent 16 hours in class, 4 hours on field trips and time outside class to complete assignments. Groups were created by the PETs themselves. In terms of prior knowledge, there were no major differences, since all PETs had taken the same subjects in the three previous years. Two of the subjects were on science education, and, in one of them, three years before the study, they had all worked on some geology concepts such as plate tectonics and geomorphology processes.

The sequence was designed by both authors that played overlapping roles of researchers and educators (Bulterman-Bos, 2008) and included a field trip and the construction of a physical model. The visited valley (Figure 1) has a circular morphology becouse there is a diapir where the gypsum and clay of the Keuper *facies* of the Upper Triassic emerge. The upper rocks are Turonian and Coniacian limestones, arranged in sub-horizontal and karstified strata, and they form the rugged reliefs of Sierra Salvada mountains. These mountains contain a karstic aquifer that drains into Nervión river. This river rises here and has eroded the mountain into a large canyon.

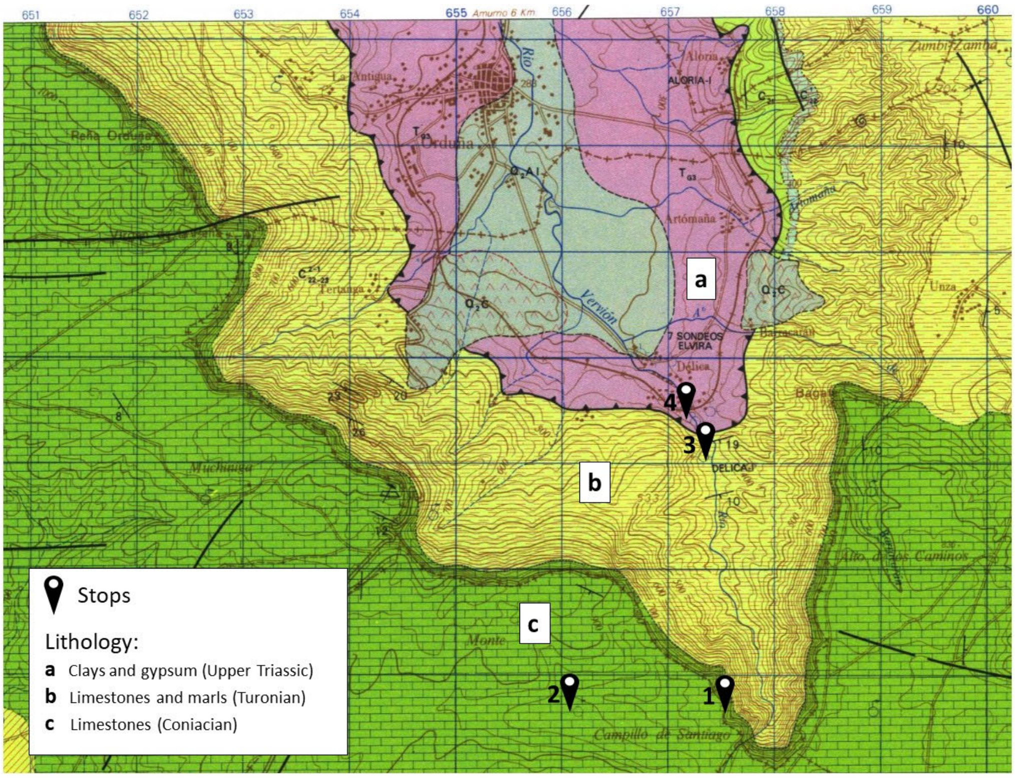


Figure 1. Geological map of the Orduña valley with the 4 stops (1-4) of the field trip (edited from Zamorano et al., 1978). The oldest unit is formed by clays and gypsum, in the centre of the valley, at the lowest elevations, in pink (a). Upper Cretaceous units, which form the highest reliefs, are represented around it: limestones and marls of the Turonian in yellow (b) and higher up, limestones of the Coniacian in darker green (c). The canyon formed by the Nervión river is visible at the bottom of the map.

This context was used for developing understanding about diapir formation and the aquifer model. This paper focuses on the modelling of the latter. For this, the activities addressed the question ‘Why does the river have water even when it does not rain?’.

Figure 2 shows the time distribution of the activities in both Years. The height of the squares represents the duration of the activity. In Year 1, the first session was devoted to the formulation of hypotheses while viewing photographs of the area. The field trip was carried out in the second session. Teachers asked PETs to observe, to formulate hypotheses, teachers did not give the answers to the main questions nor explained what they were observing. In the session following the field trip, PETs ordered the data collected in the field trip spatially and temporally, and represented them on a topographic map of the area. Subsequently, five groups constructed physical models that addressed the aquifer model. The most significant modifications in Year 2 sought to address the issue that in Year 1 there were few opportunities for PETs to revise the physical models and also to use them to make predictions and revise their mental models. They constructed and presented them, but weren´t asked to revise them. In contrast, as can be seen in Figure 2, in Year 2, the groups started to build a physical model at the very beginning. Therefore, on the field trip, they were asked to evaluate and revise this first 3D model. In addition, the teacher asked each group to constantly evaluate and revise their physical model in the subsequent sessions, focusing their attention on the evidences from the field and on the previous representations (drawings) that they had previously made themselves.

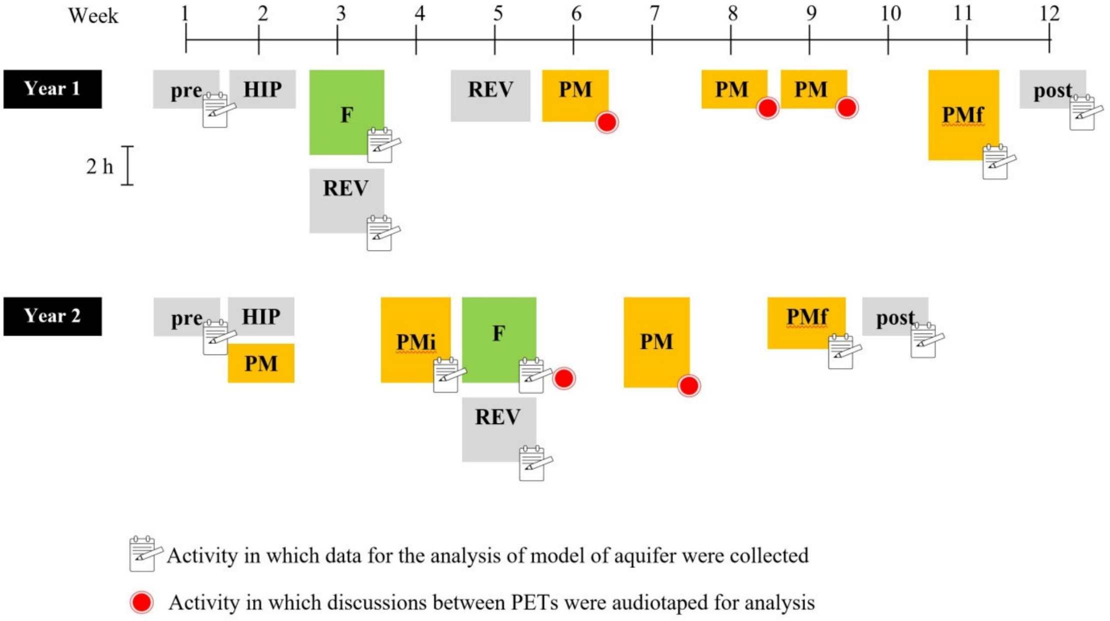


Figure 2. Week-by-week distribution of activities dedicated to the aquifer model. pre: pre-test, post: post-test, HIP: Hypothesis formulation, F: Fieldwork, REV: Revision of the fieldwork, and of the hypotheses (post-field), PM: construction/revision of the Physical Model (PM) (PMf: final 3D-model (3D-model in Year 1, 3D-model2 in Year 2), PMi: initial 3D-model1 in Year 2).

Another difference was that in Year 2, all 8 groups addressed the aquifer model, while in Year 1 there were 4 groups, as the other groups in this year addressed diapir formation instead. Therefore, in order to compare the results of Year 1 and Year 2, in the case of Year 1, only the results of the PETs addressing the aquifer model were taken into account, i.e. 22 PETs (4 groups).

### *Data collection and analysis*

The data analysed to adress the first research question were the individually written productions at the beginning and end of the sequences. Here, PETs were provided with a drawing depicting a mountain and a river, and were asked to explain the possible presence of groundwater and to add it to the drawing. Both the drawing and the written explanation were taken as a whole for data analysis. They were not segmented (Chi, 1997), but researchers searched for occurrences of the CMP dimensions of the aquifer model, based on the geological change model by Bach and Márquez (2017) and gave a score for each dimension (Table 1).

To define the levels for each component, both researchers started the analysis taking into account what they had found to be misunderstandings and the scientific model to be approached. Then researchers used constant comparative method (Lincoln & Guba, 1985) for anaysing all data and took into account the PETs` responses. To do so, both researchers analysed all data in Year 1 (pre and post productions of all 41 PETs) jointly. Then, the set of levels (Table 1) was evaluated by three experts: an expert in hydrogeology, with more than 40 years´ experience as a university professor and researcher, and two researchers in science education with more than 20 years´ experience, who had worked on the construction and use of hydrogeology models with secondary school students. As a result of the evaluation, some modifications were introduced, such as dividing Components into two: one that has to do with the geosphere, and one that takes into accout the placement of groundwater. Another modification, which dealt with the flows (Mechanisms) between the hydrogeological system and the atmosphere, was not taken into account for this paper, because the sequence had focused on the hydrogeological system, so there was no progression made by PETs for that aspect. Finally, the CMP dimensions and levels established for the analysis were those shown in Table 1.

Table 1. Definition of the different levels of each CMP dimension (0-3) for the aquifer model.

| | 0 | 1 | 2 | 3 |
|---|---|---|---|---|
| Components I (CI), underground constituents (acid water, rocks, strata, caves, porosity) | 0 | 1t | 2-3 | 4-5 |
| Components II (CII), placement of water underground | No water | Water underground | Water in cavities | Water in the porosity of the rock |
| Mechanisms II (MII), hydrogeologic flows | No connection between groundwater and surface water | Represents connection but not direction | Connects groundwater to surface water | All connections (infiltration, aquifer-river, river-aquifer) |
| Phenomena (P) | Water is not represented in coherence with its boundaries | Water in coherence with the water table. | Water in coherence with the water table and the impermeable level | In addition to level 2, it represents variations in the system due to changes in conditions |

Figure 3 shows how a complete model would be represented in a drawing.

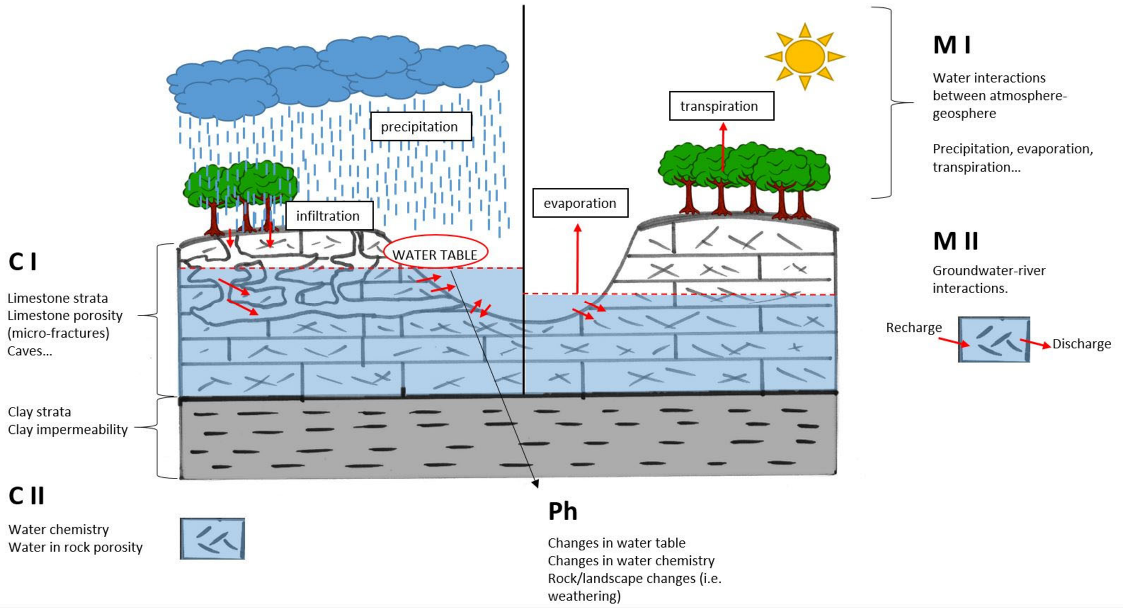


Figure 3. Drawing that shows the representation of the highest level of the dimensions of the model.

To assign a level in each dimension to each of the productions, 25% of the data from the pre- and post-questions were analysed independently by both researchers. The results were pooled and disagreements (17% of the scores for the four dimensions) were discussed and consensus reached. The first author analysed the remaining 75%, but made a continuous contrast with the second author on the analysis, specifically, all the cases that were not readily assignable to a level were discussed.

In addition to obtaining frequencies, we analysed the existence of clusters of PETs in the pre-test and post-test. These could represent typologies of PETs, taking into account their results with respect to the four CMP dimensions, using the statistical software SPSS Statistics 26.

Regarding the second research question, other representations of the model made by PETs throughout the modelling sequence were taken into account. In each of the following activities, the representations were taken as a whole for data analysis, and occurrences (Chi, 1997) of the CMP dimensions of the aquifer model were scored:

- Field: in Year 1, this consisted of an individual activity (drawing and writing). In Year 2 it consisted of a group activity (discussion and writing) at the end of the field trip, in which they revised the 3D model they had built.
- Post-field: group activity (drawing and writing).
- 3D model: group activity (physical model). In Year 1, the model presented in the last session by each group was taken into account; in Year 2, those presented prior to the field trip (3Dmodel1) and in the final session (3Dmodel2).

In addition, PET group discussions in Year 2 were used as data to address the second research question, especifically the discussions carried in the activities and moments that were purposely designed for evaluation and revision of the physical models: the first moment took place at the end of the field trip, the second, in the classroom, after the field trip. Both researchers read the transcriptions and searched for occurrences (Chi, 1997) in which PETs were revising or evaluating the physical models, or making predictions by manipulating them. In those occurrences the turn was taken as unit analysis. Teacher interventions were coded using the strategies of van der Pol et al.

(2010): feeding back, hints, instructing, explaining, modeling, questioning. The performance of epistemic practices (Jiménez-Aleixandre & Crujeiras, 2017; NRC, 2012; Santini et al., 2018) was identified in PETs´ turns.

Data collection and analysis was carried out with the favourable evaluation of this research project by the Ethics Committee for Research on Human Subjects of the corresponding university. Since the teacher was one of the researchers involved in the project, the Committee made it a condition that the students' informed consents for the use of the data be kept confidential until the subject file was closed. The condition was fulfilled.

## Results

### *Aquifer model expressed in the initial and final moments*

Tables 2 and 3 show the percentage of PETs at each level of the CMP dimensions of the model in the initial and final activities in Year 1 and Year 2 respectively.

Table 2. Percentage of PETs at each level of the CMP dimensions of the model in the initial and final activities in Year 1.

| | CI | | CII | | MII | | P | |
|---|---|---|---|---|---|---|---|---|
| | PRE | POST | PRE | POST | PRE | POST | PRE | POST |
| 3 | | | | 27.3 | | 31.8 | | 9.1 |
| 2 | | 50 | 35 | 54.5 | | 63.6 | | 4.5 |
| 1 | 35 | 31.8 | 50 | 18.2 | 45 | | | 9.1 |
| 0 | 65 | 18.2 | 15 | | 55 | 4.5 | 100 | 77.3 |

Table 3. Percentage of PETs at each level of the CMP dimensions of the model in the initial and final activities in Year 2.

| | CI | | CII | | MII | | P | |
|---|---|---|---|---|---|---|---|---|
| | PRE | POST | PRE | POST | PRE | POST | PRE | POST |
| 3 | | 5.1 | | 61.5 | | 48.7 | | 7.7 |
| 2 | 6.1 | 71.8 | 18.2 | 7.7 | 12.1 | 35.9 | | 43.6 |
| 1 | 15.2 | 15.4 | 60.6 | 30.8 | 30.3 | 10.3 | | 7.7 |
| 0 | 78.8 | 7.7 | 21.2 | | 57.6 | 5.1 | 100 | 41 |

Figures 4 and 5 show the different clusters of PETs obtained, in Year 1 and Year 2 respectively, and the averages in each dimension of the model for each cluster. The thickness of the line is proportional to the number of PETs in each cluster.

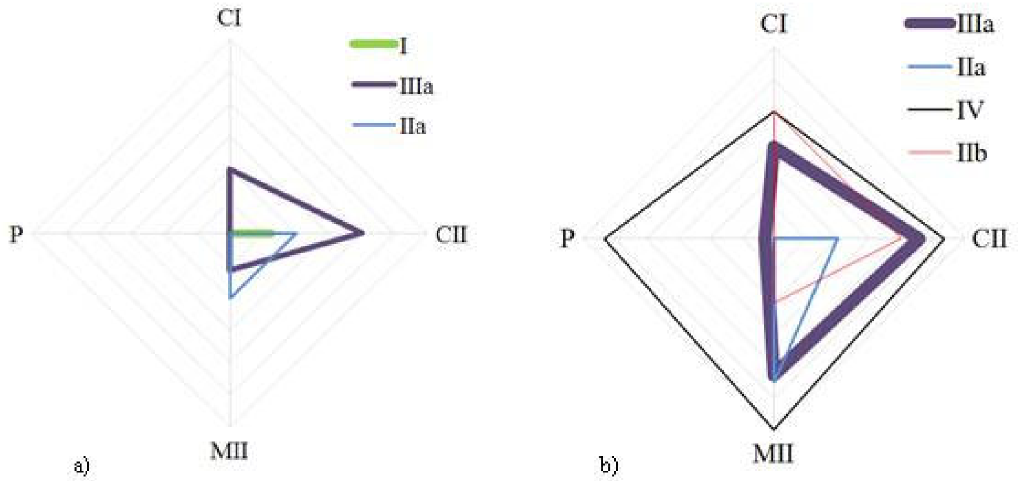


Figure 4. Clusters obtained in Year 1: a) initial responses; b) final responses.

In the initial Year 1 situation (Figure 4a), three clusters or typologies were observed. TYPE I represents 40% of PETs who only scored in CII at level 1. TYPE IIa (25%) corresponds to answers in which in addition to CII, MII was also alluded, PETs represented water in the underground and connected it to the river. TYPE IIIa corresponds to 35% of PETs who, in addition, represented some element, for example caves. In the final situation of Year 1 (Figure 4b), there were no PETs in TYPE I. TYPE IIa (18%) and TYPE IIIa (64%) were maintained, although with higher levels. Two other typologies appeared. PETs in TYPE IIb (5%) were at high levels in CI and CII: they alluded to various elements and placed water in them, but did not go beyond the Components dimension. TYPE IV (14%) represents the most complete typology: PETs with a high level in all dimensions.

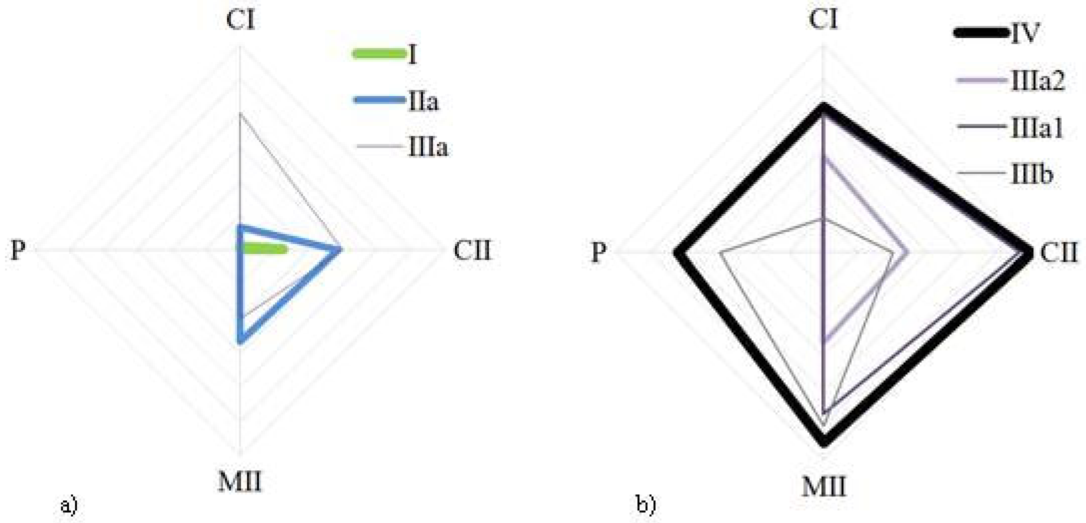


Figure 5. Clusters obtained in Year 2: a) initial responses; b) final responses.

In the initial situation of Year 2 (Figure 5a), the same typologies of Year 1 were observed although with different proportions: TYPE I (58% of PETs), TYPE IIa (36%) and TYPE IIIa (6%). In the final Year 2 situation (Figure 5b), unlike Year 1, no typologies were found that were restricted to two aspects. TYPE IIIa resulted in two groups: both scored on CI, CII and MII and not on P, but those in TYPE IIIa1 (26%) at higher levels than those in TYPE IIIa2 (15%). TYPE IIIb corresponds to 10% of PETs who, contrary to the majority, referred at low levels to Components and at higher levels to MII and P. PETs in TYPE IV (complete model) in Year 2 accounted for 49% of the total.

### *Aquifer model expressed during the modelling sequence*

Figures 6-9 show the evolution of PET performance for each dimension of the model. The size of the bubbles corresponds to the percentage of PETs.

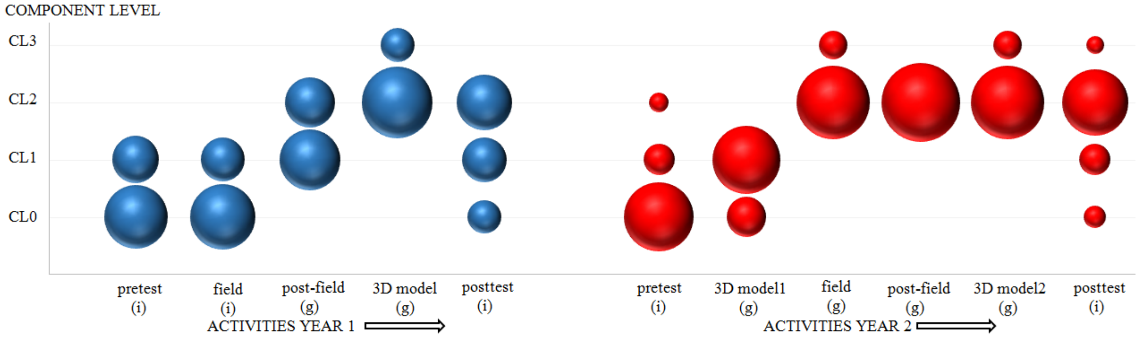


Figure 6. Percentage of PETs at each level of CI in activities during the teaching sequence in Year 1 (blue) and Year 2 (red).

As can be seen in Figure 6, in Year 1 CI improved in the post-field trip activities. In Year 2, it can be seen that the first change took place when they represented their model in the first physical model, and that all the field trip work was placed in levels 2-3.

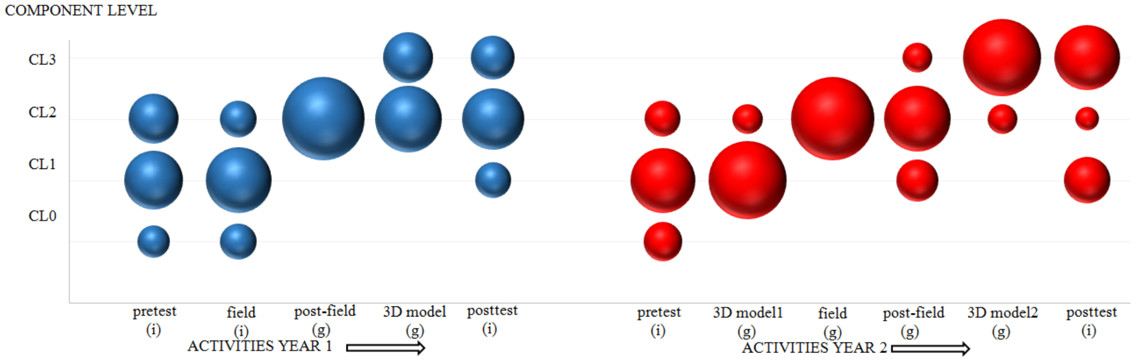


Figure 7. Percentage of PETs at each level of CII in activities during the teaching sequence in Year 1 (blue) and Year 2 (red).

CII results improved in the post-field activities compared to the pre-field activities in both Years (Figure 7). While the starting situation was similar in both Years, a higher percentage of final physical models and final individual responses in Year 2 were categorised at level 3 (87.5% of models and 61.5% of post-tests in Year 2 compared to 25% and 23.7% in Year 1 respectively). That is to say, they represented water in cracks and/or porosity in the rock. In Year 2 some of the works following the field trip were already categorised at this level.

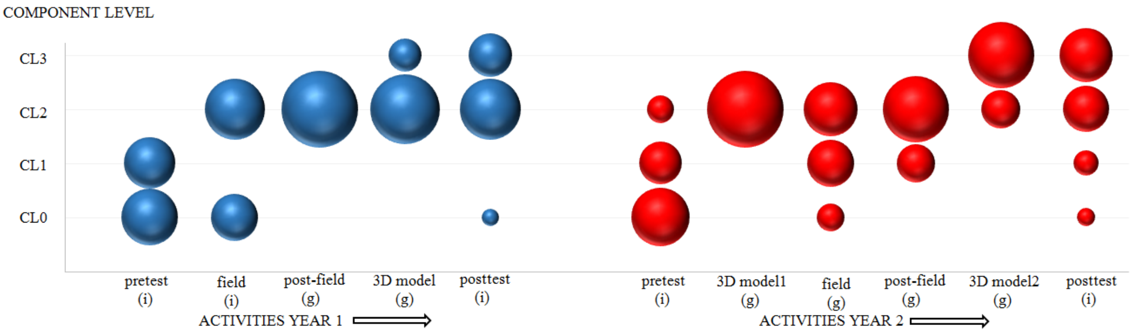


Figure 8. Percentage of PETs at each level of MII in activities during the teaching sequence in Year 1 (blue) and Year 2 (red).

With regard to the evolution of MII, the change from levels 0-1 to level 2, which corresponds to explaining that the groundwater and the river are connected and that the river is supplied by the groundwater, can be observed (Figure 8) in the field (Year 1) and in the first 3D model (Year 2). However, no results were found at level 3 until the final activities. A higher percentage of final 3D models and final individual responses from Year 2 were at level 3 (75% of 3D models and 48.7% of post-tests in Year 2 compared to 25% and 26.3% in Year 1 respectively).

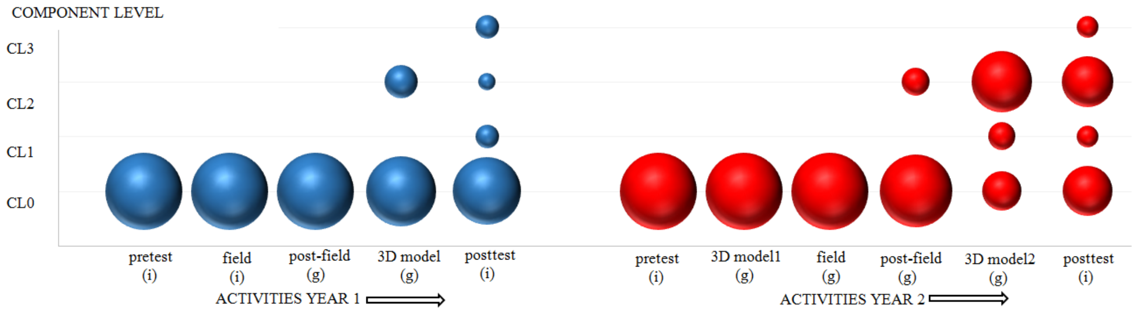


Figure 9. Percentage of PETs at each level of P in activities during the teaching sequence in Year 1 (blue) and Year 2 (red).

P was the dimension that PETs scored at the lowest levels in their productions (Figure 9). In Year 1 no PET referred to the equilibrium and change in water levels in the river and aquifer until the final 3D model and final post-tests, where they were scarce. In Year 2 one group already did so in the activity after the field trip, but the big change was observed in the final 3D models (62.5% in level 2) and in the final individual responses (43.6% in level 2 and 7.7% in level 3).

### *Evaluation/revision of the physical model (first moment, in the field)*

In the groups' conversations while evaluating the first 3D model during the field trip, based on their observations in the field, it is observed that all groups talked about the difference between the material chosen for the construction of the model (soil, sand, polystyrene, cardboard, cotton wool, sponges) and the real material (limestone rocks). The evaluation led them to justify their choice of material on the basis of its properties, for example, when they indicated that they chose soil or sand because it allows filtration.

34 Eneko: When using sand, we wanted to achieve permeability.

As observed in the discussion in group D, comparing reality with the 3D model helped them to realise their conceptual errors, such as not considering that some rocks may be permeable.

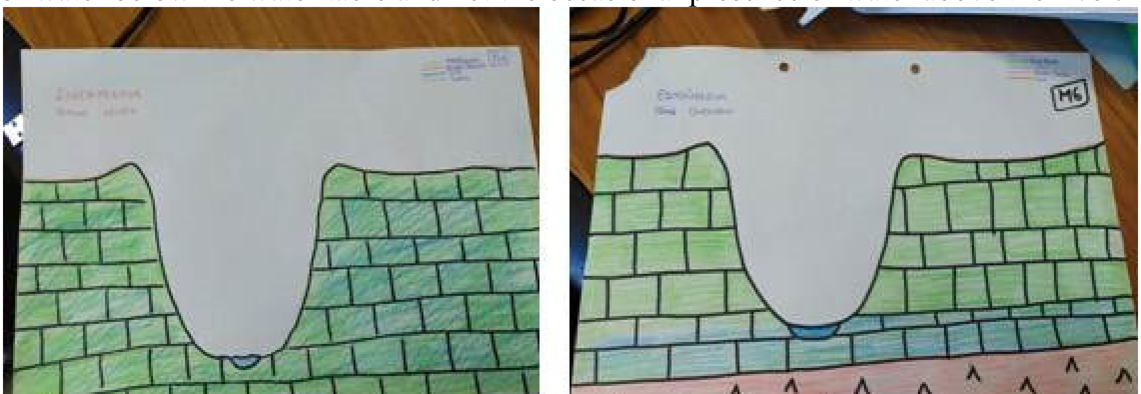
149 Diana: The thing is that we didn't know that the cause of everything is the material of the rock that is here, the type of rock that is here, which generates this, this filtration
186 Dani: We put soil and it is limestone
187 Diana: Soil which is porous and that is why the water passes through it
191 Dorleta: Okay, we thought it was soil, and in fact, it's limestone
196 Diana: Because we couldn't, maybe in our mind rock and filtration couldn´t go together
223 Dolores: That water can seep into the rock... Let's see, we thought that the internal permeable part of the mountain was soil, because for us it was unthinkable that water could seep into the rock

In addition, in the conversations, PETs were observed to strive to establish connections between the physical model and their real-world referent.

139 Flora: We can put soil and rocks and here two pieces of cardboard like this
140 Facu: And what does it [the cardboard] represent? Of course, what you are doing is, in order to achieve what you want to achieve, you put that in, but you have to achieve what is most realistically possible, so, what... What does it represent? What is it in reality?
185 Facu: You can put a piece of cardboard so that [the water] goes there, but what does the cardboard represent?

### *Evaluation/revision and manipulation of the physical model (second moment, in the classroom)*

As mentioned, before modifying the initial physical model or making a new one, the groups had represented in a drawing the materials and structures in the field and their hypothesis of how the river carries water even if it does not rain (Post-field activity). As can be seen in Figures 6, 7 and 8, the model expressed by groups showed quite high levels in three dimensions (CI, CII, MII) but the results for P (Figure 9) were poor. Thus, the drawings showed no water table or coherence between the water table and the river. PETs, indeed, overemphasised the presence of water above the river and underestimated the role of water below the river, as represented in Figure 10a. Figure 10b, instead, shows the river coherent with the water table and highlights the presence of water below the water table and not the occasional presence of water above the river.



a) b)

Figure 10. Drawings of group F a) before building the physical model, b) at the end of the session.

PETs were asked to take the drawings as starting points for the 3D models, so that when building and using them, the incoherences would become salient. In all groups, discussions took place between the teacher and the PETs about the choice of material to represent the riverbed. All groups initially represented the riverbed using some impermeable material (aluminium foil, plastic bottles, plastic film...), which, on the one hand, did not correspond to what the groups themselves had previously represented in the drawing. Moreover, this did not correspond to what was observed in the real river, whose riverbed was made of limestone, and worse still, made it difficult to represent the formation of the aquifer and its water supply to the river in the 3D model. With the scaffolding given by the teacher, PETs changed this in the 3D models and all groups constructed physical models that allowed the introduction of water in the system and predictions to be made. Figure 11 shows the physical model constructed by group D.

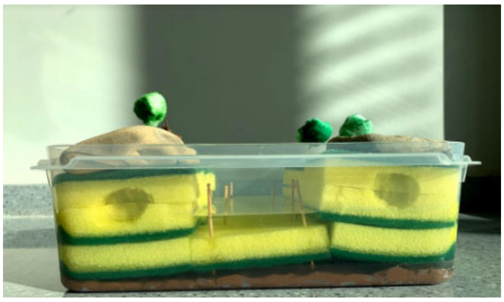


Figure 11. Physical model constructed by group D (after pouring water).

In this respect, the situation of the models was similar to that of Year 1. However, in Year 1, even though the physical model allowed for manipulation and making predictions, PETs had not been instructed to do this, and indeed did not. In fact, they hardly manipulated their physical models at all. In contrast, in Year 2, PETs had to manipulate their physical models, they had to pour water on them, and the teacher scaffolded PETs while doing so. She used questioning, for example, in interventions 124, 131 and 135 in group H, especifically in 131 and 135 so that PETs had to manipulate the physical model and use it to make predictions. In 132, 134, 136 it can be seen that PETs performed that epistemic practice.

124 Teacher: More rain, more rain… What´s up with this?
126 Harkaitz: They are wet.
131 Teacher: And in two hours? In two days?
132 Harkaitz: The rocks will dry out but…
133 Teacher: These will be dry
134 Harkaitz: All [water] will be filtered
135 Teacher: It will filter downwards, how far?
136 Harkaitz, Hugo: Down to the clay

This scaffolding led PETs to learn what an aquifer is and how an aquifer and a river can form (interventions 136, 143, 153, 163 in group H show the diverse boundaries they determine to construct the explanation), and to evaluate their own previous ideas (see intervention 165).

142 Teacher: Where is the water?
143 Hugo: Up to here

153 Harkaitz: And the river up to here
162 Teacher: And, what is the aquifer?
163 Hector: That one, all that
165 Hector: We had put it at the top, and it's not at the top, it's at the bottom

The teacher used questioning for PETs to make predictions and explain in all the groups. As can be seen in group E, the group got to understand what the water table is, where it is, and then in interventions 85-88 they take the same strategy the teacher had done: one of the members uses questioning, his partner explains what is happening in the various parts of the physical model.

73 Teacher: What will happen here [top of the mountain]?
74 Edu: It will dry out.
75 Eva: The water table will drop
76 Teacher: Where is the water table?
77 Eneko: Right now, up there
79 Teacher: No
80 Emilio: No, down, all the way down
81 Eneko: Ah no, it´s true!
83 Edu: It´s here [Figure 12, left]
85 Edu: So, the cave we have here [Figure 12, right], how is it?
87 Eneko: Dry
88 Edu: Empty

Figure 12. Screen captures of the videotaped construction of the physical model in group E.

Some of the PETs, for example in group A, acknowledged how useful it was for them to make the 3D model:

401 Aitor: We had misunderstood it, eh
403 Aitor: Until now, until we have not done so...
404 Amaia: Yes, she is right that you learn from the physical model

## Discussion and Conclusions

The focus of this work has been the evolution of the aquifer model of two cohorts of PETs. The starting point in the two years analysed shows that the PETs presented the shortcomings already pointed out in the literature. They gave little importance to the structural components related to the geosphere, had difficulties in considering rocks to have porosity and permeability (Arthurs & Elwonger, 2018; Unterbruner et al., 2016) and confused the nature and position of aquifers: most thought that water is found in hollows such as caves, as other studies found (Dickerson & Dawkins 2004; Pan & Liu, 2018; Sadler et al., 2016; Unterbruner et al. 2016) especially above river level, but were less aware that it is also in the porosity of the rock soaking down to the water table. Thus, they did not take into account the relationship of the river level to the water table.

Despite the limitations of the study, which as a case study does not provide generalisable results, the results show that the modelling sequences designed in this study helped the participants to improve their aquifer model, especially in Year 2. In both Years, PETs had more difficulties in Mechanisms and Phenomena than in Components dimensions, which was also found by Ben-Zvi Assaraf and Orion (2005b). At the end of Year 1, PETs still showed major deficiencies in terms of the Phenomena, which in this case corresponded to how the aquifer and river are formed and the consistency they show with the impermeable rock below and the water table. However, in Year 2 PETs built a more complete aquifer model. Indeed, the results were better in all CMP aspects of the model. In fact, all PETs in Year 2 showed a final model in which at least three dimensions were represented, and the percentage of PETs with good levels in all four was 49%, while in Year 1 it was 14%. PETs have difficulties understanding the formation of the aquifer. One of them is related to the fact that, although water can be found in caves in karstified limestones, water is also in the porosity of the rocks. As some of PETs acknowledged in the field, it is hard for them to think about rocks containing water in their porosity. Another difficulty is to comprehend that the aquifer is situated below the water table, that the level of the river corresponds to the water table, and so water above the water table is just passing through. Conversations while constructing the physical model in Year 2 show that PETs acknowledge that they had this difficulty and that they overcame it. These are relevant misunderstandings that make awareness (Ben-Zvi Assaraf & Orion, 2005a) and understanding of society´s problems, such as depletion of groundwater, seawater intrusion or contamination of aquifers (IPCC, 2021), extremely difficult. Year 2 PETs were better prepared than those in Year 1 to make decisions about such problems.

We consider that these better results in Year 2 were favoured by the attention given to the model revision stage in the modelling process (Gilbert & Justi, 2016; Schwarz et al., 2009). The mentioned revision was based on the evaluation of the physical model against reality, and on the manipulation of the model to simulate phenomena and make predictions. For this purpose, the objective of the field trip was modified and the teacher used scaffolding strategies, mainly questioning (van der Pol et al., 2010) for PETs to manipulate and revise their physical models to make predictions.

One of the objectives of the Year 1 field trip was to observe reality and obtain data to formulate hypotheses and to guide the subsequent construction of the physical model (Uskola & Seijas, 2021). However, in Year 2, as observed in the conversations between PETs at the end of the field trip, the data obtained were used to evaluate the physical model already constructed. Thus, all groups contrasted the material used with the real material, but not only did they find that they were different, but more interestingly, they justified their choice of material on the basis of the property they wanted to represent, i.e., permeability. In addition, they realised their conceptual errors, such as not considering that some rocks may be permeable. The results show that, in fact, the dimensions CI and CII improved in Year 2 in the field and in the activities immediately after. Moreover, in the field conversations, it is observed that the PETs internalised the function of the physical model as a representation of reality, and it is seen that they critically analysed what the elements they used in their construction represented, comparing the physical model and reality.

Searching for correspondences and noncorrespondences between the physical model and reality is “an often overlooked component of modeling practice” (Miller & Kastens, 2018, p. 641) but the results of the present study support the conclusion of Kastens and Rivet (2010) who pointed out that “some of the most profound learning opportunities arise if and when students critically examine the correspondences and non-correspondences between the classroom model and the Earth system" (p. 122). We would add that in order to compare the physical model with the Earth system, the field trip is a very valuable educational resource, as can be seen in the results, which support the perspective of Fedesco and Cavin (2020), Mogk and Goodwin (2012), among others.

The second key moment for the construction of the aquifer model, after the field trip, was the revision and manipulation of the physical model. While in Year 1, the PETs were encouraged to do this, in Year 2 the teacher went group by group, and used scaffolding strategies, mainly questioning (van der Pol et al., 2010) for PETs to perform epistemic practices (Jiménez-Aleixandre & Crujeiras, 2017; NRC, 2012; Santini et al., 2018) such as evaluating their physical models comparing them with reality, constructing explanations about what was happening when they introduced water into the physical models to simulate the phenomenon, making predictions about what might happen, and evaluating their learning process. Teacher scaffolds have proved to be important and even essential for learning. In the case of open-ended activities, Hardy et al. (2006) indicated that students may focus on the activity itself and not reflect on the relevant concepts, so they may not reach the intended scientific conclusions or may even acquire disorganised, incomplete knowledge or even conceptual errors (Kirschner et al. 2006). This may be what happened in Year 1: the PETs only had conversations about manipulative issues, were focused on the activity of building the physical model and did not reflect on the phenomenon it represented. The teacher in Year 2, as observed in the conversations, helped the PETs become aware, during the construction of the physical model, of its function both as a representation of the model and as a tool for making predictions (Gilbert et al., 2000). She first helped them to assess whether the physical model represented their initial mental model (represented in the drawing), and, once they had, she helped them to revise that model with the aid of the physical model. None of the PETs had a complete model before constructing the physical model, and it was not until they manipulated and made predictions with it, scaffolded by the teacher, that they were able to understand, for example, how an aquifer or a river are formed and what changes these can undergo and why. The results show that PETs were able to take advantage of the potential of physical models (Gómez et al., 2007) as mediators between the students' initial ideas and the phenomena, and between the different levels of the students' model in the process. For this, it was very relevant that the PETs had constructed and revised their physical models, which confirms the need to incorporate this type of activities in geology teaching (Gray et al., 2011; Torres & Vasconcelos, 2016). It is expected that PETs who have experienced learning in ways consistent with how they are expected to teach (Zembal-Saul, 2009), will, in their future science teaching, foster their students´ modelling by using physical models as tools for reasoning rather than merely as communication aids (Miller & Kastens, 2018), and as tools for thinking, reasoning and exploring theoretical ideas (Torres & Vasconcelos, 2016).

## Ethical Statement

The study was approved by the Ethics Committee for Research on Human Subjects of the UPV/EHU CEISH-UPV/EHU (M10_2019_146 research project, approved 18 July 2019 (115/2019)).

## Funding

This work was supported by the Euskal Herriko Unibertsitatea UPV/EHU [grant number GIU19/008].

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