Journal of Turkish Science Education, 2024, 21(2), 271-292.
DOI no: 10.36681/tused.2024.015

Journal of Turkish Science Education
http://www.tused.org
© ISSN: 1304-6020

Evolution of the living being model in Spanish pre-service teachers: first implementation of design research

Rosa Esperanza Galera-Flores[1], Natalia Jiménez-Tenorio[2], José María Oliva[3]

[1] *University of Cádiz, Spain, Corresponding author, rosa.galera@uca.es, ORCID ID: 0000-0003-4092-9167*
[2] *University of Cádiz, Spain, ORCID ID: 0000-0001-7879-9877*
[3] *University of Cádiz, Spain, ORCID ID: 0000-0002-2686-6131*

ABSTRACT
This study is the first phase of an on-going study. It shows the first implementation of a teaching-learning sequence designed to facilitate the understanding of the notion of a living being in initial teacher training using modelling approaches. It aims to analyse the knowledge progression of the participants (N=51) through a retrospective analysis, employing an open-ended questionnaire and a rubric. To achieve this, a comparative pre-test-post-test design was used, utilising an open-ended questionnaire. The results show progression in the management of the living being model after comparing knowledge before and after implementation. The results suggest the usefulness and interest of the modelling approaches in teaching this topic, while also highlighting the need for modifications to the didactic sequence employed.

RESEARCH ARTICLE

ARTICLE INFORMATION
Received:
23.06.2023
Accepted:
31.07.2023

KEYWORDS:
Retrospective study;
pre-service teachers;
living being.

To cite this article: Galera-Flores, R.E., Jiménez-Tenorio, N., & Oliva, J. M. (2024). Evolution of the living being model in Spanish pre-service teachers: first implementation of design research. *Journal of Turkish Science Education*, *21*(2), 271-292. DOI no: 10.36681/tused.2024.015

Introduction

Biology, a core subject at school, involves the study of living beings and the processes that take place in them (Sammet & Dreesmann, 2017). This may explain why the number of publications on biology education has increased in recent years (Abdullah, 2022). Defining life is necessary to understand the development of living organisms. Despite the fact that there are several definitions for it, they are mainly based on biological properties such as adaptation, reproduction, evolution, metabolism, response to stimuli, or the transfer of characters from one generation to the next (Tetz & Tetz, 2020).

Living being, at various levels of complexity, is studied at both primary and secondary school. Students often have confusing ideas about living beings due to the high level of abstraction this notion involves (Mora, 2019). Some studies have identified similar difficulties among pre-service teachers as well as the alternative conceptions they develop. Examples of these difficulties include differentiating between feeding and nutrition (Mondelo et al., 1998), understanding the interconnectedness of all the processes involved in nutrition (Reinoso & Delgado-Iglesias, 2020), recognising the cell as the functional and structural unit of a living being (Maguregi, 2013), and associating vital functions with plant organisms (Kurt et al., 2013; Mengascini, 2005; Schussler & Olzak, 2008). It is therefore necessary to develop and test teaching approaches that help overcome these difficulties, especially in teacher training.

The design and evaluation of Teaching-Learning Sequences (TLS) is not only a common practice in teaching, but is also a field of study through design-based research approaches (Plomp, 2013). This type of research not only aims to theoretically underpin and contextualise the developed didactic designs but also involve the evaluation of the results obtained from them. It focuses on modifying and improving the TLS for future implementations.

This research is part of a broader study based on the design and evaluation of a teaching sequence regarding the living being model, guided by modelling approaches, and aimed at pre-service teachers. In this case, the impact of a teaching-learning sequence on students' understanding was analysed during an initial implementation cycle, and the understanding demonstrated by the students regarding the notion of a living being was compared before and after the implementation of the sequence in order to assess its effectiveness.

The research questions were:

1. What knowledge did the participants show regarding the school living being model before and after the TLS?

2. What progress, if any, was made by comparing the knowledge before and after the TLS?

The aim of answering these questions is not only to evaluate the TLS used, but also to define possible changes and improvements to introduce to the sequence in a second implementation.

Theoretical Framework

The importance of understanding how scientific knowledge is produced and tested is widely agreed upon in science education (Crujeiras & Jiménez-Aleixandre, 2012). In the case of the initial training of Spanish primary school teachers, this is particularly important as the majority of future teachers come from a non-scientific background and do not usually take science subjects throughout their teacher training programme. This results in them having numerous deficiencies in their scientific knowledge and holding alternative conceptions, in many cases similar to those held by primary and secondary school learners. Therefore, it is important to focus on how preservice teachers overcome these initial conceptions and are able to organise their knowledge around a model consistent with that of school science. Hence, we theoretically position this study in the realm of models and modelling in science.

Models are representations of objects or phenomena that allow predicting or explaining situations, and testing theories (Gilbert et al., 2000; Svoboda & Passmore, 2013). They are hence used as tools in science to express theories and establish connections with the real world (Giere, 2001; Morrison & Morgan, 1999; Oh & Oh, 2011), promoting the understanding of the phenomenon or system studied (Soulios & Psillos, 2016). However, despite their usefulness, they cannot be considered exact replicas of the reality they try to represent. They are partial and simplified representations that help understand reality from certain viewpoints (Gilbert & Justi, 2016). They are easier to interpret and provide additional information or features of the represented system that may not be observable (Acevedo-Díaz et al., 2017).

Models are basic elements of the school science curriculum, given their usefulness to build, test and evaluate scientific knowledge (Acevedo-Díaz et al., 2017). Model-based teaching and modelling represent a whole family of interesting approaches to science teaching, which provide learners not only with learning models, but also with reasoning processes when they are engaged in the construction, use, evaluation and modification of models (Gilbert & Justi, 2016). The students' mental models need to be taken as a starting point, considering them as representations built from previous experiences and conceptions (Shepardson et al., 2007). Through teaching, those models should then evolve towards models that are closer to those of science (Galera-Flores et al., 2023a; Clement, 2000; Hernández et al., 2015). In this regard, an important task of science teaching consists of the didactic transposition of scientific models so as to transform them into school models, which should be the real references for learning (Izquierdo-Aymerich & Adrúriz-Bravo, 2003).

Modelling-based science teaching is an appropriate approach for the knowledge progression of learners with regard to school science models, and it also promotes reflective and collaborative work around scientific practices (Oliva, 2019).

In biology, models are used for a variety of purposes and uses depending on the context (Svoboda & Passmore, 2013). It is present throughout the entire educational process, and it is therefore interesting to look for teaching approaches that are based on models, and that can be adapted to the different educational levels. Initial knowledge, based on superficial learning, would hence progress towards deeper knowledge, allowing learners to ask questions about, or solve problems in daily life (Clement, 2000; Gómez, 2014).

The model to be applied to living beings is one of the most significant ones for school science. This notion is closely related to the concept of life: the living being is the agent in which life processes take place. This model can be approached in several ways. One of them, according to Morgavi et al. (2005) is from the presence of intrinsic dynamic phenomena of self-regulation, such as the capacity of self-maintenance (self-renewal, homeostasis, adaptation, etc.), self-transformation, and self-transcendence (development, evolution, etc.). For his part, Gómez-Márquez (2021) defines living beings using the criteria of homeostasis and dynamics. Homeostasis refers to the ability to maintain a stable internal environment, while dynamics concerns the interaction that occurs between and within systems, which involves processes of evolution. Momsen et al. (2022) define a living organism from a systemic perspective, giving it the capacity to acquire, use, and transform energy and matter. According to them, a living organism can store, use and transfer genetic information, as well as receive or perceive information regarding the environment and respond to it.

Taking these premises into account, this research approaches the modelling of living beings from an integral viewpoint, working both on its structural and functional aspects. Thus, it is understood as a complex system structured by one or more cells, capable of performing vital functions: exchanging matter and energy with the environment (nutrition), detecting stimuli and responding to them (interaction), producing new individuals, repairing, structuring and transferring characteristics to descendants (reproduction) (García, 2007).

When examining the chosen model of living beings in-depth, we observe that the concept of the cell is a key for the understanding of biological organisation in the teaching of biology (Cohen & Yarden, 2010), since all living organisms are made up of cells, some by one and others by millions. It is considered the basic unit of the living being in which biological functions ultimately take place (Tanner & Allen, 2002). With regard to vital functions, nutrition is the one that occurs in all cells, where an exchange of matter and energy between the organism and the environment occurs (García, 2007). Reproduction, for its part, allows the production of new individuals, the repair or growth of structures, and the evolution or adaptation of population. It is therefore conceived at different levels: cellular, individual, and population (García, 2017; Gómez-Márquez, 2021). Finally, interaction is the ability of living beings to detect stimuli and respond to them and, as a result, to adapt to different circumstances, which is an opportunity to evolve (Gómez-Márquez, 2021). These three functions are related.

The integrating perspective of the model to be presented enables talking about a living being, a living organism, or a complex biological system, interpreting it as a set of elements that interact with each other and in which those interactions may affect the entire system (Gilissen et al., 2021). This system perspective is useful when it comes to learning biological processes, since it allows conceiving the interactions that take place between and within the different levels of biological organisation. Learners should recognise and use these hierarchical levels in a reasoned manner, identifying both microscopic entities, like cells, and macroscopic ones, such as organs, systems or populations, amongst others (Knippels & Waarlo, 2018).

Despite the fact that the different ideas constituting the living being model is addressed at various educational levels, numerous difficulties are associated with their understanding. With respect to the structural component of the model, a low understanding of the cellular level, of identifying cellular components, and of the cell's role in nutrition, cellular respiration, or reproduction processes, cell division, repair, growth and heredity was observed (Banet & Ayuso, 2000; Camacho et al., 2012; Lewis et al., 2000). Regarding the functional component, difficulties have been observed associated with the vital functions, such as differentiating nutrient from food, recognising the integration of the digestive, respiratory, circulatory, and excretory systems in human nutrition, differentiating external respiration from the process of cellular respiration, recognising biological functions in plant organisms such as photosynthesis, or identifying the reproduction and interaction functions in plant organisms, amongst others (Badenhorst et al., 2016; Marmaroti & Galanopoulou, 2006; Özay & Öztaş, 2003; Parker et al., 2012; Reinoso & Delgado-Iglesias, 2020).

Focusing on initial teacher training, several authors describe difficulties related to the notion of living beings. Pre-service primary teachers tend to have erroneous ideas about various aspects of living beings (Kurt, 2013). For example, it is observed that, in general, future primary teachers have a tendency to conceptualise life from animistic and anthropocentric perspectives, and find it easier to identify animals than plants as living (Çil & Yanmaz, 2017). In Spain, Reinoso & Delgado-Iglesias (2020) assessed pre-service primary teachers' knowledge regarding the systems involved in nutrition. Apart from some anatomical errors, those authors observed alternative conceptions associated with this function, such as considering that digestion starts in the stomach, confusing the urinary system with the digestive system, or identifying respiration as a mechanical process of inhaling oxygen and exhaling carbon dioxide without considering the need for oxygen to get to the cell to generate energy. In another study, similar conceptions were observed (Mondelo et al., 1998), since future primary teachers mainly use macroscopic aspects such as breathing, eating, or moving in their definitions of living beings, and to a lesser extent those related to cellular physiology, not mentioning the cell or the processes in which it intervenes. In addition, difficulties were observed with regard to the use of terms such as food and nutrition, to identifying movement, or to detecting stimuli in plants. Maguregi (2013) observed difficulties when pre-service primary teachers had to identify seeds as living beings, and recognise the cell as the basic unit of life.

Research Context

As mentioned before, the purpose of this study is to implement and evaluate a teaching sequence centred on living being, employing modelling approaches, and specifically designed for preservice teacher's primary. Following Galera-Flores et al. (2023a), the didactic principles used in the design of the TLS were:

1. Adopt the living being model as described in the theoretical framework, understanding it as a complex system made up of cells, capable of performing the three vital functions of nutrition, reproduction and interaction. This means the TLS is structured into four blocks: definition of a living being (B1), function of nutrition (B2), function of reproduction (B3) and function of interaction (B4).
2. Establish a progressive itinerary from simple to complex models, going through a series of learning milestones
3. Establish links between theory and reality, connecting models with experience
4. Structure the sequence following a modelling approach based on the phases described by Sanmartí (2000) in the design of sequences: exploration of the problem studied and explanation of initial ideas; introduction of new ideas; structuring of learnt knowledge; knowledge application, and self-regulation. These phases were adopted as references when developing modelling cycles and sub-cycles (Couso & Garrido-Espeja, 2017).
5. Include instrumental resources of the modelling process, especially analogies, mental experiments, and simulations
6. Include group and individual methodology activities, encouraging the active and reflective participation of students

The contents of the TLS were organised around 34 learning references (R) necessary to get a comprehensive view of a model for living beings (Table 1).

Table 1

Learning references

Notion	Learning references
Living being	Living organisms are not only humans and other animals. There are five kingdoms: animal, plant, fungi, monera and protist (R1). Living beings are complex systems made up of cells capable of performing the three vital functions: nutrition, interaction and reproduction (R2). There are other characteristics of living beings, but they do not define. For example, the life cycle, which must be differentiated from vital functions (R3). Vital functions are essential for defining a living organism. They must be understood both independently and in relation to one another (R4).
Cell	The cell is the structural unit of living organisms (R5). The cell is the functional unit of living beings because it performs the three vital functions (R6). There are different types of cells: prokaryotes, animal eukaryotes, and plant eukaryotes (R7). Organisms can be unicellular (one cell) or multicellular (more than one cell) (R8).
Nutrition	Nutrition, whose purpose is to exchange matter and energy with the environment, is a process carried out by all living beings (R9). In human nutrition (and some other animals), the digestive, circulatory, respiratory, and excretory systems are involved, and all of them are connected (R10). The function of nutrition is not simply the digestive process, but also includes other processes (R11). The terms 'organic nutrient' and 'food' are not the same, as food undergoes a series of changes during digestion until it turns into nutrients (R12). Gas exchange during breathing is exchanging the oxygen (O_2) necessary for the production of energy, expelling carbon dioxide (CO_2) as waste (R13). Respiration in plants, like in any organism, occurs in the same way as in humans (R14). Plants synthesize nutrients through photosynthesis, producing oxygen. Some of this oxygen is used to obtain useful energy, while the rest is expelled (R15). There are organisms, such as fungi, that decompose organic matter by directly taking organic nutrients from the environment (R16). Both nutrients and oxygen must be transported to all cells of the organism (R17). In the cell, O_2 and organic nutrients react, generating energy and waste products (CO_2 and water) (R18). Excretion is the elimination of the substances produced in the cellular metabolism, and not of the useless substances of the digestive system (R19).
Reproduction	Reproduction is an essential function to maintain life (R20). Every living organism comes from another organism (R21). Reproduction goes beyond having offspring (R22). Reproduction occurs at three levels: microscopic (cellular) for the repair and growth of the individual (R23); macroscopic (individual) for producing new individuals, and perpetuation of species (R24); and complex (population-environment) to maintain populations in a changing environment, and transfer of characters, that is, adaptation and evolution (R25). There are organisms that reproduce asexually and/or sexually (R26).

	There are advantages and disadvantages in the two types of reproduction related to energy expenditure, number of participants, genetics, and survival (R27). Cell division occurs in two differentiated processes: mitosis and meiosis (R28). A hermaphrodite has a male and female reproductive system (R29).
Interaction	The function of interaction is the ability of living beings to detect stimuli and respond to them (R30). The nervous/endocrine system, the locomotor system, and the sense organs intervene in the function of interaction in humans and animals (R31). There are cells that detect stimuli, transmit the information, process it, prepare a response, and execute it (R32). Plants are also related through processes such as phototropism (R33). Organisms, including fungi and bacteria, detect changes that occur in the environment, and act taking advantage of them (R34).

Based on the didactic principles and the aforementioned learning references, a TLS consisting of 13 sessions of one and a half hours each, and 25 activities, was designed. In Table 2, each activity is described, and it is related to the block, the session, and the learning reference it belongs to.

Table 2

Teaching-learning sequence

Block	Session	Activity	Description	Learning reference
B1, B2, B3, B4	1	1-Initial questionnaire	Exploration of students' initial ideas about living beings.	All
B1	2	2-Do we know living beings?	Individual representation of the initial models.	R1, R2, R3, R4
		3-Let's move forward as a group	Comparison of models identifying different degrees of complexity. Providing a definition from a series of given concepts.	R1, R2, R3, R4
		4-Let's develop our model.	Redesigning the model of living beings.	R1, R2, R3, R4
	3	5-This is a living being.	Comparison of the model created with a simple model of living beings.	R1, R2, R3, R4, R5, R6
		6-What goes on in another living being?	Application of the model and comparison of cells.	R1, R2, R5, R7, R8
B2	4	7-Time to eat!	Restructuring of the nutrition process in the human being, including the four systems involved in it.	R6, R9, R10, R11, R12, R13, R17, R18, R19
	5	8-How do we feed ourselves?	Representation of the nutrition process in a drawing.	R9, R10, R11
		9-How do other organisms feed themselves?	Approaching the nutrition process in fungi and plants, using drawings.	R9, R14, R15, R16
	6	10- Summarising nutrition	Preparing a final nutrition model.	R9

B3	7	11-What do we know about reproduction? 12-Who is who?	Explaining the need for living beings to reproduce. Comparison of sexual reproduction in humans and plants (analogy).	R20, R22, R23, R24, R25 R24, R29
	8	13-Let's start growing things!	Reflection on the existence of organisms with the two types of reproduction: sexual and asexual (thought experiment).	R26
		14-From parents to children	Explaining how sexual and asexual reproduction occur and what the differences between them are.	R23, R24, R25, R26, R27, R28
	9	15-Analysing reproduction in more detail	Introduction of the concept of growth and repair in reproduction.	R6, R23, R28
		16-Let's experience things *in situ*.	Inclusion of environmental factors in the evolution process (simulation).	R25
		17-Time to act!	Approaching the reproduction process in fungi and spontaneous generation (thought experiment).	R21
B4	10	18-Let there be light!	Comparison of the function of interaction of the human being with the functioning of a lamp (analogy).	R6, R30, R31, R32
	11	19-What would happen?	Applying the knowledge learnt regarding the function of interaction to organisms of other kingdoms (thought experiment).	R30, R31, R33, R34
B1, B2, B3, B4	12	20-Joining ideas. Everything is connected.	Reflection on the connection between the three vital functions.	R4
		21- Time to apply knowledge!	Checking the functionality of the cell.	R5, R6, R18, R23, R32
		22-Let me introduce you to Sophie	Review of the knowledge learnt in a non-living being (robot).	All
		23-Let's develop a final model	Characterising the final model of living beings, comparing it with the initial model.	All
		24-Are they living beings?	Verifying the model developed using a virus.	All
	13	25-Final questionnaire	Preparing a final questionnaire on living beings.	All

Note. B1: block 1; B2: block 2; B3: block 3; B4: block 4.

Methods

Type of Research

This study is framed within a design-based research study regarding a TLS aimed at improving the knowledge of future primary school teachers about the living being model. This kind of research is defined as the analysis of a problem, development and refinement of a design through iterative cycles, and a final evaluation (Reeves, 2006). After successive cycles, the evaluation process thus generates an improved design to enhance the learning of a specific topic (Guisasola et al., 2021, Psillos & Kariotoglou, 2016, Plomp, 2013). Three differentiated phases are considered in design studies: a first preparatory phase aimed at the design of a TLS; a second one for implementation aimed at putting the design into practice with a group of students, and a third one for evaluation dedicated to carrying out a retrospective study on the impact of the implementation on student learning. Previous studies focused on the first two phases (Galera-Flores et al., 2023a, Galera-Flores et al., 2023b), while the present study is dedicated to the third phase, analysing the results obtained after a first implementation cycle.

Participants

The TLS was implemented with a group of 58 students who were enrolled in Didactics of Natural Sciences I, taught during the third year of the Bachelors' Degree in Primary Education at University of Cádiz. The sample consisted of 42 female and 16 male students, most of whom (76%) had not taken any science subjects since they were 14-15 years old.

The TLS was implemented during academic year 2021-2022 between October and January, and took place in the usual classroom, where the students met up to work in 13 groups of 4 to 5 members each. In the classroom, students worked individually as well as in small groups and large groups. Although 58 participants took part in the study, data were obtained from only those 51 students who completed the initial and final questionnaires of the TLS.

Data Collection Instrument

To answer the research questions, an open-ended questionnaire was used. It consists of nine questions and was divided into two parts (Appendix I). The first part focuses on defining the criteria used to define life and the living being, as well as identifying examples thereof. The second part refers to the vital functions. The students had to explain and identify according to specific examples of each function in this part.

The questionnaire underwent evaluation by six experts in science education and/or science teachers. Additionally, the questionnaire was piloted with a preliminary sample of teaching students to verify the clarity of the statements and make necessary wording modifications (Galera-Flores et al., 2023b).

Only those learning references that were key to understanding the notion of living beings were included in the questionnaire. Table 3 shows the references evaluated in each question of the questionnaire. A total of 22 of the 34 references considered, which is almost two thirds, were evaluated.

Table 3

Learning references addressed in the questionnaire

Questions	Description	Learning reference
1 and 2	Structural and functional definition of the model	R2, R4, R5, R6
3	Identification of examples	R1
4	Distinguishing reproduction in the illustrations	R23, R24, R25, R26
5	Definition of reproduction	R20, R21, R23, R24, R25
6	Distinguishing interaction in the illustrations	R30, R31, R32, R33
7	Definition of interaction	R30, R31, R32
8	Distinguishing nutrition in the illustrations	R9, R13, R15, R18, R19
9	Definition of nutrition	R9, R10, R17, R18

Data Collection Procedures

The questionnaire was administered at the beginning and end of the proposal enabling a comparison of results to assess the progress made in students' knowledge during the TLS. The collected data for each question allowed for evaluation across nine different dimensions. Because questions 1 and 2 in the pilot study yielded very similar results, they were evaluated together, although two different dimensions were distinguished: the structural dimension (SD), referring to the notion of cell, and the functional dimension (FD), related to the vital functions of reproduction, interaction and nutrition. The remaining seven dimensions (D3 to D9) corresponded to the answers to the questions of the same number.

Data Analysis Process

First, the information derived from the considered dimensions was subjected to analysis using a pre-established rubric. Each dimension was evaluated on an ordinal scale containing four levels, in which level 4 was the most advanced, and level 1 corresponded to blank or superficial responses (Appendix II). The response categorisation process was carried out independently by two researchers who previously agreed on the criteria to be used. Consensus was achieved in 92.6% of the cases in the pre-test, and in 93.7% in the post-test, having a Kendall Tau-b value ranging between 0.820 and 0.999, being statistically significant in all cases at a level of $p<0.001$.

Secondly, the validation of the rubric was tested through Rasch analysis (1960) using Winstep software v. 4.4.7 (Linacre, 2020). For this purpose, the procedure proposed by Wright (2003) was followed, stacking the results from the pre-test and post-test. The analysis showed appropriate values for the Infit and Outfit parameters, consistently falling within the range of 0.5 to 1.5, as suggested by Linacre (2002). Specifically, Infit values ranged from 0.67 to 1.42, while Outfit values ranged from 0.65 to 1.19. This indicates the absence of local dependence or background noise. Additionally, the polychoric correlations of each dimension with the total were quite high, ranging from 0.58 to 0.81, suggesting unidimensionality in the measurements. Moreover, the reliability for student measurements yielded a value of 0.85, while for the dimensions, it reached a value of 0.96. Lastly, the four-level scales employed exhibited a monotonic behaviour, thus indicating a coherent ordering relationship among the different categories or response levels of the scale.

Finally, a quantitative analysis was performed through statistical tests using the SPSS programme. Frequency tables were used to characterise the types of responses provided by the students in the pre-test and post-test, as well as the Wilcoxon statistical test to analyse whether or not the students' responses improved in the post-test compared to the pre-test.

Findings

The results of this study provide information on the initial knowledge of the participants regarding the idea of living beings, and how this knowledge progressed towards a model of living beings closer to the school model used as a reference in the TLS.

Participants' Knowledge Before and After the TLS

The results obtained from the questionnaire before and after the implementation are presented in Figures 1 and 2. It shows that in the pre-test the students' answers were located mainly in the lowest levels (1 and 2) in most of the dimensions analysed, level 4 being practically non-existent. In contrast, the results achieved in the post-test reflected that the majority of their responses were located in higher levels, level 3 being the most frequent in six of the nine dimensions analysed, and level 4 in two of the remaining three dimensions.

Figure 1

Response percentage in the pre-test (N=51)

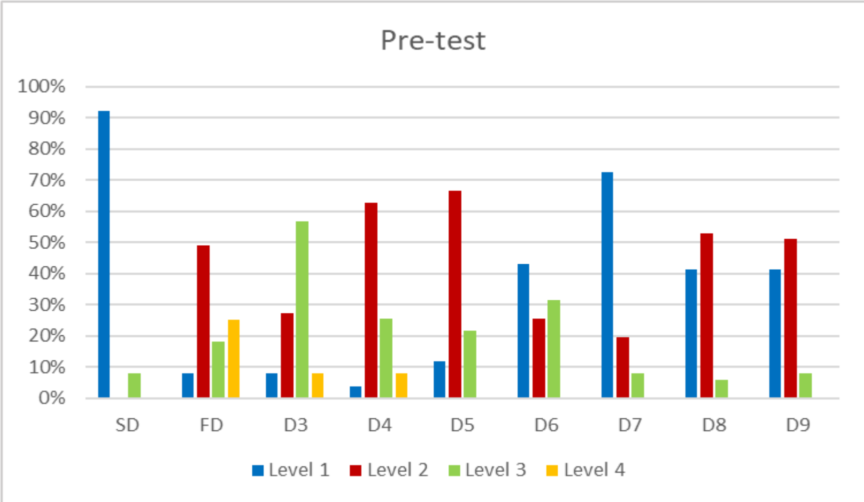
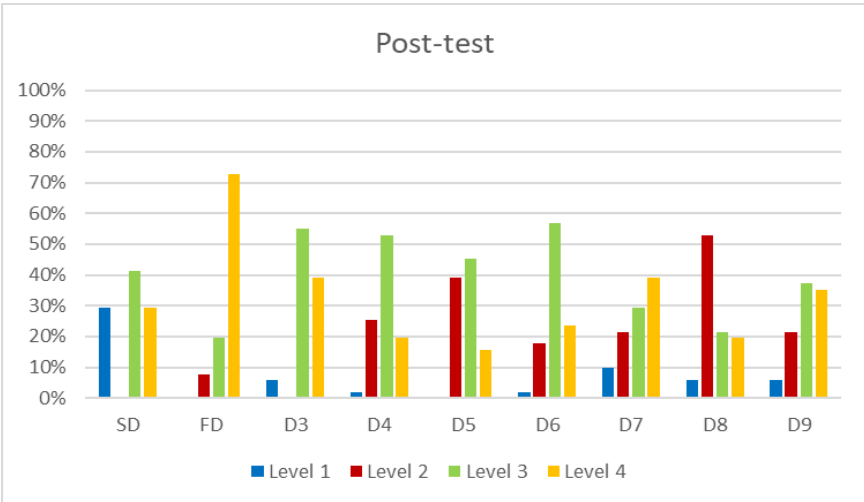


Figure 2

Response percentage in the post-test (N=51)



Regarding the structural dimension (SD) of the model, it was observed that the vast majority of the participants' answers (92%) was located in level 1 in the pre-test, as the students did not use the notion of cell when defining living beings. Meanwhile, 8% associated the presence of the cell as a requirement for something to be considered a living being, although the students did not identify it as the most basic unit of life. As an example, the literal response of a student is shown: "[...] and it is made up of cells."[1] (level 3).

These results improved in the post-test when the response rate in level 1 decreased significantly. It was 29% after the implementation, while the percentage of students' responses located in level 3 increased, reaching 42%. Responses appeared in level 4, reached by 29% of the participants.

[1] The English phrases presented in this article were used to illustrate students' responses. The equivalence of meaning between English and Spanish was verified through back-translation to ensure translation accuracy.

In other words, after completing the sequence, 71% of the participants were able to associate a cell with a living being, and a large number of students even defined the cell as the structural and functional unit of a living being:

> "Something that is alive is a living being, and is therefore made up of one or more cells." (level 3).
>
> "The basic functional unit of which is the cell [...]." (level 4).

The students seem to know the functional dimension (FD) better, since, from the beginning, the proportion of level 1 responses was very low at 8%. Meanwhile, approximately half of the students defined the model of living beings using its characteristics, but not vital function:

> "[...] first we are born, then we reproduce, and then we die." (level 2).

A total of 18% of the students added vital functions to these criteria (level 3), and 25% were able to provide an appropriate and detailed functional definition (level 4). Like in the previous dimension, a considerable improvement was also observed in this dimension after completing the training sessions. In the post-test, although level 2 responses continued to be present, the proportion dropped significantly, representing only 8% of the answers, while the responses in level 4 increased to 73%:

> "[...] should perform the three vital functions (nutrition, obtaining energy; interaction, responding to stimuli; reproduction, ability to create offspring, or generate more cells in the same body." (level 4).

Dimension D3, which focuses on providing examples from different kingdoms, seemed to have been the least difficult one for the students. Initially, the highest percentage, 57%, was obtained in level 3. However, 35% of the students' responses were located in the lower levels (1 and 2). This shows the students were not able to give examples of more than two different kingdoms, mostly animals and plants. After implementing the TLS, this dimension evolved positively, and the responses located in level 4 increased substantially (from 8% to 39%). In other words, after the sequence, a large number of participants –almost four out of ten students– was able to name all the kingdoms in which living beings are organised. However, the persistence of responses in level 1 (6%) is striking. This means some students continued to mention only examples of animals.

The next two dimensions, D4 and D5, are related to the function of reproduction. In both cases, the students' responses were mostly found in level 2 (63% and 67% respectively), which shows the students only recognised this function in a single aspect, usually the production of new individuals. This means the students lacked a complex view of the said function that included the cellular environment:

> "It is a vital function in which, from one or two individuals, others appear." (level 2).

Subsequently, in the post-test, a significant decrease was observed in both dimensions in the number of student responses located in level 2 (25% and 39% respectively), and a considerable increase in levels 3 (53% and 45%) and 4 (20% and 16%). It can thus be inferred that the results improved after the training sessions. The students were able to identify the function of reproduction in two or even three levels (cellular, macroscopic, and population). Examples of these two levels in D5 are the following:

> "[…] is in charge of the continuity of the species, in addition to its evolution in the case of sexual reproduction. In asexual reproduction, there is no genetic recombination and, therefore, no evolution" (level 3).
>
> "[…] is one that is produced asexually (a single individual) or sexually (in which two individuals are necessary), and serves to produce new individuals, as well as new structures of these individuals. Sexual reproduction increases the diversity of species and ensures their evolution. Some cells reproduce asexually by mitosis, and the daughter cells are the same as the mother cells" (level 4).

In dimensions D6 and D7, related to the function of interaction, it is observed that the largest percentage in both dimensions initially corresponds to level 1 (43% and 72% respectively). In both dimensions, responses are also found in levels 2 and 3, but the percentages in D6 are higher (26% in level 2, and 31% in level 3), in comparison to D7 (20% and 8%). In this last dimension, the example shown in illustration B (pulling one's hand away from the fire) (Appendix I) was the one the students used the best to explain this function, since 96% of the students who gave a detailed answer did so for this illustration, and 28% of them also used another one. With respect to the definitions provided in D7, the following examples were found:

"Relationship of a living being with the environment through which an action is carried out" (level 2).

"[...] is the one that allows adapting to the environment by creating certain responses depending on the stimulus received" (level 3).

In the post-test, better results were obtained in both dimensions, as level 1 was reduced to almost zero percentages in both dimensions (2% and 10% respectively), and level 4 emerged, attaining the percentage with the highest value in D7 (39%):

"It allows a living being to detect (internal or external) stimuli and produce (motor or secretory) responses to them. In the case of humans/animals, the stimulus is perceived by the senses, the brain coordinates and sends a response to that stimulus to the locomotor system, which executes the response" (level 4).

Both in the pre-test and the post-test, it was observed that the students experienced greater difficulty in defining this function than in identifying it in specific examples. Moreover, despite the fact that illustration B continued to be the one the students used the best (67%), in most cases (seven out of ten) they also used some other illustration, and 25% of the students identified this function in all the examples proposed.

Finally, in the dimensions referring to nutrition, D8 and D9, almost identical percentages were observed in the pre-test. In both cases, the students' responses were located mainly in levels 1 (41% in both dimensions) and 2 (53% and 51% respectively). The students explained it as the exchange of matter or of energy, but not of both:

"It is the function in charge of providing energy to the body, necessary to carry out the two vital functions mentioned above." (level 2).

This was also expressed by the students in D8, to a greater extent, in illustration D (person with drip), followed by illustrations A (woman breathing) and B (tree in the sun) (Appendix I).

These results improved in both dimensions in the post-test. A considerable decrease in level 1 (6% in D8 and D9), as well as an increase in level 3 (22% and 37%) was observed, and level 4 appeared (20% and 35%). This means the students were able to identify this function as the exchange of matter and energy, and even provided a detailed answer:

"[..] the function by which we obtain nutrients to have energy to be able to live" (level 3).

"…function by which living beings incorporate nutrients and oxygen into the body, so that their cells transform them into energy in order to grow and continue performing vital functions" (level 4).

Here, in D9 the students used all the illustrations better in general, since four out of ten students identified this function as an exchange of matter and energy in all the illustrations shown, and in the rest of the cases they used illustration A (50%) together with another one (Appendix I).

Participants' Knowledge Progression

In order to analyse, in quantitative terms, the knowledge progression of the pre-service students with regard to the model of living beings, their performance in the pre-test and post-test was compared using the Wilcoxon statistical test (Table 4). It shows that the majority of the students, ranging from 51% to 84% depending on the dimension, progressed in their knowledge after completing the TLS. They advanced the most in the function of interaction (D6 and D7), while the function of reproduction was the one in which they made the least progress (D4 and D5). The level of progress in the function of nutrition (D8 and D9) was situated in between that obtained for the other two functions. With respect to the structural and functional levels (SD and FD), the students' progress was also remarkable and similar in both cases. Finally, as far as the exemplification of living beings (D3) was concerned, slightly less progress was made, although it was still substantial. Furthermore, it was observed that few students did worse, although a significant fraction, ranging from 14% to 45%, made no progress.

In general, the progress achieved was statistically significant ($p<0.001$) between the pre-test and the post-test in all the dimensions of the rubric. Therefore, we may conclude that there was an improvement in the students' management of the model of living beings after implementing the TLS.

Table 4

Wilcoxon statistical test (pre-test and post-test), N=51

	SDPost-SDPre	FDPost-FDPre	D3Post-D3Pre	D4Post-D4Pre	D5Post-D5Pre	D6Post-D6Pre	D7Post-D7Pre	D8Post-D8Pre	D9Post-D9Pre
Negative rank	1	1	4	5	2	1	1	3	3
Positive rank	34	35	28	28	26	39	43	34	37
Tie	16	15	19	18	23	11	7	14	11
Z	-5.127	-5.228	-4.214	-4.012	-4.353	-5.253	-5.766	-4.908	-5.364
p-value	.000	.000	.000	.000	.000	.000	.000	.000	.000

Note. N: sample size; Negative rank: frequency of students whose level is lower in the post-test; Positive rank: frequency of students whose level is higher in the post-test; Tie: frequency of students who remain at the same level.

Discussion

The trial TLS was designed to be implemented with future primary school teachers to improve their knowledge of the notion of living beings. The results of this research were overall satisfactory, although it was observed that not all the students fully reached the school science model proposed for this topic.

With regard to the definition of living beings and life provided by the students, we initially observed they used ideas that were far from the school science model of living beings. They gave answers that were superficial, or related to common aspects of humans and animals, coinciding with what is reflected in the bibliography (Amprazis et al., 2019; Anggoro et al., 2008; Galera-Flores et al., 2023b; Martínez-Losada et al., 2013; Özgür, 2018; Venville, 2004). The vast majority of the students did not mention the cell, which shows they did not identify it as the smallest unit of life, and this coincides with the findings of other studies (Camacho et al., 2012; Maguregi, 2013). This constitutes a major problem, since understanding the notion of cell is a basic requirement for understanding a large number of concepts in biology (Simsekli, 2018). Furthermore, a lot of students did not identify more than three kingdoms, mainly the animal kingdom, and to a lesser extent plants and fungi. A significant number of students only distinguished organisms from one kingdom, the animal kingdom, as was observed by Çil & Yanmaz (2017). This finding aligns with the results obtained by Amprazis et al. (2021), who noted that students face challenges in identifying other living organisms, such as plants, from an early age.

However, after the implementation of the TLS, the students demonstrated a notable improvement in their use of appropriate criteria when defining living organisms, reflecting the effectiveness of the TLS in guiding their understanding. Both from a structural and functional viewpoint, the students identified the cell as the basic unit of life, and the vital functions as a requirement to define living beings (R2), the two pillars on which the school science model is based. Likewise, the students were able to name more kingdoms, and they were able to mention the majority of organisms from four or five different kingdoms. Therefore, the activities of the TLS as a whole seem to have been successful in promoting the students' knowledge progression regarding living beings.

Yet, it is necessary to improve the references related to identifying organisms from the five kingdoms (R1) in activity 6, or to differentiating the life cycle and vital function (R3) in activity 5, as the students continued to have difficulties in internalising these aspects.

Regarding the functional component of the model, and starting with the function of reproduction, it was initially observed that the students had problems in identifying it in the three levels proposed. Hence, their responses mainly referred to the process of producing offspring, without mentioning the cellular level, such as the process of growth or repair of structures in which cell division is involved. These results are in line with previous studies that have found that pre-service teachers have misconceptions about the reproduction of living beings (Emre & Bahsi, 2006; Kurt et al., 2013; Tekkaya et al., 2000). A possible explanation is that these aspects tend to be dealt with in little detail in compulsory education, where this function is usually focused on aspects related to health and sexual education (García, 2017).

Nevertheless, participating in this TLS allowed students to distinguish the three levels of action, and was reflected both in the activities they engaged in and in the questionnaires. Nonetheless, despite the fact that the results show progression in the students' knowledge and management of this function, difficulties associated with the microscopic component and the processes of evolution and adaptation persisted, considering levels 2 and 3 are the most representative in this function. At least, this is what the responses given in the post-test show, coinciding with what was observed by Camacho et al. (2012) in secondary school students.

As for the function of interaction, it was initially the function the students understood the least (reflected in the high percentage of responses located in level 1 in the two corresponding dimensions of the pre-test), although it was also the function in which the students made the most progress after it was taught. A possible reason could be that this function is hardly addressed in the different educational stages, and the elements that intervene in it are addressed in a disconnected manner in Spanish schools (Gómez, 2014). In our research, we observed that, although initially the students understood it as a process of communication or interaction with individuals of the same species, at the end of the TLS they used appropriate criteria to define it. In other words, the knowledge regarding this function improved significantly, which leads us to conclude that the activities related to this function seem appropriate to achieve a satisfactory progression of the students' models, and the acquisition of learning references associated with it. This represents supporting evidence for the effectiveness of TLS, considering the significance of the function of relationship as a mediator between the other two functions, thus favouring a systemic view of the concept of a living being. In fact, a system is nothing more than a collection of elements that interact with each other, functioning as a whole and generating effects within the system through the interaction of its parts (Gilissen et al., 2021).

The answers provided for the function of nutrition revealed that the students tended to have a fragmented idea of this function. At the beginning, they explained it as a process in which only the digestive system takes part, although some students also included the circulatory system, but without identifying the interconnection that occurs throughout the process with these or other organs and systems. These results coincide with what is pointed out by Reinoso & Delgado-Iglesias (2020), who also observed pre-service teachers were partially or totally unaware of the structures and/or processes involved in nutrition. Also, they align with the results obtained by Brown & Schwartz (2009), who detected that preservice primary teachers were limited in their understanding of the connections among biological systems at macro and micro levels of photosynthesis and plant cellular respiration.

However, a positive aspect observed was that there are student responses in level 2 referring to energy, although the most common is matter. This shows that a percentage of the students did not consider it exclusively as a process of taking in food, but also identify the purpose of energy exchange it implies.

Lastly, the statistical analysis confirmed that the TLS helped improve the model of living beings the students managed, since progress was made in all the dimensions after the TLS, especially in the function of interaction, where they advanced the most despite the difficulties initially encountered. The statistical analysis also revealed that the students responded better to the questions asked about vital functions when it came to identifying them in specific examples than when they had to provide a definition, except for the function of nutrition, which had a different pattern. This outcome is undeniably promising, as the literature suggests that numerous learning challenges regarding the concept of living organisms persist among preservice teachers (Bonil & Pujol, 2008). Thus, in this case, the implemented design principles seem to have had a positive effect on student learning, especially in the case of those principles that promoted the use of modelling-based teaching approaches (Gilbert & Justi, 2016; Oliva, 2019) or those that addressed the need to approach the concept of living beings from a complex perspective (Momsen et al., 2022; Pujol, 2003).

Conclusions and Implications

A retrospective analysis is presented after the first implementation of the TLS. The results obtained in the pre-test revealed significant deficiencies in students' understanding of the living beings model. This was evident through the occurrence of poor, disorganised, or superficial responses, as well as the presence of alternative conceptions. However, it is important to note that the pre-test results serve as a baseline for assessing students' initial knowledge and understanding. However, the results show progression in the management of the model of living beings after comparing knowledge before and after implementation (pre-test and post-test), although the proposed school science model of living beings was not formulated in its entirety in all cases. As shown, the TLS seems to contribute to improving the model of living beings the students managed. It allowed them to identify the essential requirements to define the life of any organism. In general, the students' responses improved considerably at the end of the TLS, and they managed to express a model similar to that of school science.

Despite the fact that the results obtained are promising, the knowledge expressed by the students does not fully conform to the model of living beings proposed. This may be due to the complexity this notion involves, but also to deficiencies in the TLS reflected in the difficulties encountered during its implementation regarding the microscopic aspects of the model, or notions such as photosynthesis. Aspects were found that may improve the proposal, adjusting it to the needs of the students. Introducing changes to the TLS with the aim of developing new implementation cycles is considered good practice, hence closing the stages in which design-based research is developed. The aim is for the cycles to resemble the result or purpose for which they were developed. Thus, analysing the results of the implementations determines the strengths and weaknesses of the TLS, and the opportunities for improvement with a view to implementing new cycles in the future.

In this regard, since our objective is for students to achieve a model close to that of school science, we believe that the TLS should be modified as there is room for improvement. In future implementations, we will attempt to develop in more detail the activities that address learning references related to microscopic components about sexual and asexual reproduction at the cellular level and processes of evolution and adaptation (R23, R25, R27, R28). Additionally, emphasis should be placed on the purpose of nutrition (R9), the identification and connection of systems involved in human nutrition (R10), the role of oxygen (O2) in energy generation (R13), and the role of the cell in this process (R17).

Furthermore, in our proposal of modifications, we intend to replace some of the activities, modify others, and add some new ones. For instance, activities 6 and 13 should be replaced by others, as they do not fulfil the purposes for which they were intended. The statement in activity 5 should also be improved to obtain more explicit responses from the students when they compared the initial model that they formulated to the one that emerged from the work done in the classroom. To do this, the statement should be restructured, and should include subsections that allow to better contextualise the activity, guiding the students' attention and reflection, and applying their ideas better. Changes will also be introduced to the statement of activity 7, modifying the order of appearance of the questions included, and eliminating others. Finally, it is considered necessary to include a new activity that helps mobilise knowledge regarding respiration in plant organisms, as it is observed alternative conceptions about this process persist after the TLS.

A second-generation TLS, including all the aforementioned changes, will be developed, implemented, and evaluated with a group of students that have similar characteristics to the group involved in this study. It will allow us to check if the changes introduced contribute to better results, and what other changes would need to be made in subsequent implementations.

Acknowledgements

The authors received financial support from Spanish Ministry of Science and Innovation (Grant/Award Reference: PID2022-136353NB-I00).

Declaration of Interest Statement

The authors declare that there is no conflict of interest.

References

Abdullah, K. H. (2022). Publication trends in biology education: a bibliometric review of 63 years. *Journal of Turkish Science Education, 19*(2), 465-480. https://doi.org/0.36681/tused.2022.131

Acevedo-Díaz, J. A, García-Carmona, A., Aragón-Méndez, M. M., & Oliva-Martínez, J. M. (2017). Modelos científicos: significado y papel en la práctica científica [Scientific models: meaning and role in scientific practice]. *Revista Científica, 30*(3), 155-166. https://doi.org/10.14483/23448350.12288

Amprazis, A., Papadopoulou, P., & Malandrakis, G. (2019). Plant blindness and children's recognition of plants as living things: a research in the primary schools' context. *Journal of Biological Education, 55*(2), 139-154. https://doi.org/10.1080/00219266.2019.1667406

Anggoro, F. K., Waxman, S. R., & Medin, D. L. (2008). Naming practices and the acquisition of key biological concepts: evidence from English and Indonesian. *Psychological Science, 19*(4), 139-144. https://doi.org/10.1111/j.1467-9280.2008.02086.x

Badenhorst, E., Mamede, S., Abrahams, A., Bugarith, K., Friedling, J., Gunston, G., & Schmidt, H. G. (2016). First-year medical students' naïve beliefs about respiratory physiology. *Advances in Physiology Education, 40*, 342-348.

Banet, E., & Ayuso, E. (2000). Teaching genetics at secondary school: a strategy for teaching about the location of inheritance information. *Science Education, 84*(3), 313-351.

Bonil, J., & Pujol, R. M. (2008). Orientaciones didácticas para favorecer la presencia del modelo conceptual complejo de ser vivo en la formación inicial de profesorado de educación primaria [Guidance to favour the presence of the complex conceptual model of living being in the initial training of teachers]. *Enseñanza de las ciencias, 26*(3), 403-418.

Brown, M. H., & Schwartz, R. S. (2009). Connecting photosynthesis and cellular respiration: Preservice teachers' conceptions. *Journal of Research in Science Teaching, 46*, 791-812. https://doi.org/10.1002/tea.20287

Camacho, J. P., Jara, N., Morales, C., Rubio, N., Muñoz, T., & Rodríguez, G. (2012). Los modelos explicativos del estudiantado acerca de la célula eucarionte animal [Explanatory models about the eukaryotic cell by secondary school students]. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias, 9*(2), 196-212. http://dx.doi.org/10.25267/Rev_Eureka_ensen_divulg_cienc.2012.v9.i2.03

Clement, J. (2000). Model based learning as a key research area for science education. *International Journal of Science Education, 22*(9), 1041-1053. https://doi.org/10.1080/095006900416901

Cohen, R., & Yarden, A. (2010). How the curriculum guideline "The Cell is to be studied longitudinally" is expressed in six israeli junio high school. *Journal of Science Education and Technology, 19*(3), 276-292.

Couso, D., & Garrido-Espeja, A. (2017). Models and modelling in pre-service teacher education: why we need both. In K. Hahl, K. Juuti, J. Lampiselkä, A. Uitto & J. Lavonen. (Ed.), *Cognitive and affective aspects in science education research*. Selected Papers from the ESERA 2015 Conference (pp. 245-261). Springer.

Crujeiras, B., & Jiménez-Aleixandre, M. P. (2012). Participar en las prácticas científicas [Participate in scientific practices]. *Alambique, 72*, 12-19.

Crujeiras, B., & Jiménez, M. P. (2018). Influencia de distintas estrategias de andamiaje para promover la participación del alumnado de secundaria en las prácticas científicas [Influence of different scaffolding strategies for engaging secondary students in scientific practices]. *Enseñanza de las ciencias, 36*(2), 23-42. https://doi.org/10.5565/rev/ensciencias.2241

Çil, E., & Yanmaz, D. (2017). Determination of pre-service teachers' awareness of plants. *International Electronic Journal of Environmental Education, 7*(2), 2017, 84-93.

Emre, I., & Bahsi, M. (2006). Misconceptions of science teacher candidates about cell division. *Eastern Anatolia Region Research Journal*, 4, 70-73.

Galera, R. E., Oliva, J. M., & Jiménez-Tenorio, N. (2023a). Estudio de progresión de saberes personales y consensuados en torno a la noción de ser vivo en estudiantes para maestros [Study of personal and consensual knowledge progression around the notion of living being in student teachers]. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias 20*(2), 2103. https://doi.org/10.25267/Rev_Eureka_ensen_divulg_cienc.2023.v20.i2.2103

Galera-Flores, R. E., Oliva, J. M., & Jiménez-Tenorio, N. (2023b). Rúbrica para evaluar el saber acerca del modelo de ser vivo en maestros en formación [Rubric to evaluate the knowledge about the living being model in training teachers]. *Góndola, enseñanza y aprendizaje de las ciencias, 18*(2), 210-228. https://doi.org/10.14483/23464712.18920

García, P. (2007). Els models, organitzadors del currícul en biología [Models, organisers of the biology curriculum]. *Ciències, 6*, 29-33.

García, S. (2017). La reproducción desde la ciencia escolar [Reproduction from the perspective of school science]. *Alambique Didáctica de las Ciencias Experimentales, 88*, 7-13.

Giere, R. N. (2001). A new framework for teaching scientific reasoning. *Argumentation, 15*(1), 21-33.

Gilbert J. K., & Justi R. (2016). *Modelling-based teaching in science education*. Springer.

Gilbert, J., Boulter, C., & Elmer, R. (2000). Positioning models in science education and in design and technology education. In J. K. Gilbert & C. J. Boulter. (Ed.), *Developing Models in Science Education*. Springer.

Gilissen, M. G. R., Knippels, M. C. P. J., & Van Joolingen, W. R. (2021). Fostering students' understanding of complex biological systems. *CBE-Life Sciences Education, 20*(3), 1-15. https://doi.org/10.1187/cbe.20-05-0088

Gómez, A. A. (2014). Progresión del aprendizaje basado en modelos: la enseñanza y el aprendizaje del sistema nervioso [Progression of learning based on models: teaching and learning about the nervous system]. *Bio-grafía, 7*(3), 101-107.

Gómez-Márquez, J. (2021). What is life? *Molecular Biology Reports, 48*, 6223-6230. https://doi.org/10.1007/s11033-021-06594-5

Greca, I. M., Meneses, J. A., & Diez, M. (2017). La formación en ciencias de los estudiantes del grado en maestro de Educación Primaria [Science training of the students of the degree in Primary Education teacher]. *Revista Electrónica de Enseñanza de las Ciencias, 16*(2), 231-256.

Guisasola J., Ametller J., & Zuza K. (2021). Investigación basada en el diseño de secuencias de enseñanza-aprendizaje: una línea de investigación emergente en enseñanza de las ciencias [Designing teaching-learning sequences with design-based research: an emerging research line in science education]. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias, 18*(1), 1801. http://doi.org/10.25267/Rev_Eureka_ensen_divulg_cienc.2021.v18.i1.1801

Hernández, M. I., Couso, D., & Pintó, R. (2015). Analyzing students' learning progressions throughout a teaching sequence on acoustic properties of materials with a model-based inquiry approach. *Journal of Science Education and Technology, 24*, 356-377. https://doi.org/10.1007/s10956-014-9503-y

Izquierdo-Aymerich, M., & Adúriz-Bravo, A. (2003). Epistemological Foundations of School Science. *Science & Education, 12*, 27-43. https://doi.org/10.1023/A:1022698205904

Knippels, M. C. P. J., & Waarlo, A. J. (2018). Development, uptake, and wider applicability of the yo-yo strategy in biology education research: A reappraisal. *Education Sciences, 8*(3), 129. https://doi.org/10.3390/educsci8030129

Kurt, H. (2013). Biology student teachers' cognitive structure about "Living thing". *Educational Research and Reviews, 8*(12), 871. https://doi.org/10.5897/ERR2013.1408

Kurt, H., Ekici, G., Aksu, Ö, & Aktaş, M. (2013). Determining cognitive structures and alternative conceptions on the concept of reproduction (the case of pre-service biology teachers). *Creative Education, 4*(9), 572-587. http://dx.doi.org/10.4236/ce.2013.49083

Lewis, J., Leach, J., & Wood-Robinson, C. (2000). What's in a cell? Young people's understanding of the genetic relationship between cells, within an individual. *Journal of Biological Education, 34*(3), 129-132. https://doi.org/10.1080/00219266.2000.9655702

Linacre, J. M. (2002). What do infit and outfit, mean-square and standardized mean? *Rasch Measurement Transactions, 16*, 878.

Linacre, J. M. (2020). *A user's guide to Winsteps/Ministeps Rasch model programs*. MESA Press.

Maguregi, G. (2013). El modelo de ser vivo: una secuencia indagativa con alumnado del grado de Educación Primaria [The model of living things: an enquiry-based sequence performed with students of the primary education degree]. *Enseñanza de las Ciencias*, n. extra, 2075-2081.

Marmaroti, P., & Galanopoulou, D. (2006). Pupils' understanding of photosynthesis: A questionnaire for the simultaneous assessment of all aspects. *International Journal of Science Education, 28*(4), 383-403. https://doi.org/10.1080/09500690500277805

Martínez-Losada, C., García-Barros, S., & Garrido, M. (2013). How children characterise living beings and the activities in which they engage. *Journal of Biological Education, 48*(4), 201-210. https://doi.org/10.1080/00219266.2013.849281

Mengascini, A. (2005). La enseñanza y el aprendizaje de los tejidos vegetales en el ámbito universitario [Teaching and learning of plant tissues in the university environment]. *Revista Electrónica de Enseñanza de las Ciencias, 4*(2), 1-17.

Momsen, J., Speth, E. B., Wyse, S., & Long, T. (2022). Using systems and systems thinking to unify biology education. *CBE-Life Sciences Education, 21*(2). https://doi.org/10.1187/cbe.21-05-0118

Mondelo, M., Martínez, C., & García, S. (1998). Criterios que utilizan los alumnos universitarios de primer ciclo para definir ser vivo [Criteria university students in their first years use to define living things]. *Enseñanza de las Ciencias, 16*(3), 399-408.

Mora, N. J. (2019). Propuesta didáctica para enseñar conceptos asociados al modelo 'ser vivo' en nivel medio. [Didactic proposal for teaching concepts related to the model of living beings 'in secondary education]. *Educación en Ciencias Biológicas, 4*(1), 10-22. http://repositorio.cfe.edu.uy/handle/123456789/579

Morgavi, G., Morando, M., Biorci, G., & Caviglia, D. D. (2005). Growing up: emerging complexity in living being, *Cybernetics and Systems: An International Journal, 36*(4), 379-395. http://dx.doi.org/10.1080/01969720490929382

Morrison, M., & Morgan, M. S. (1999). Models as mediating instruments. In M. S. Morgan & M. Morrison. (Ed.), *Models as mediators* (pp. 10-37). Cambridge University Press.

Oh, P. S., & Oh, S. J. (2011). What teachers of science need to know about models: an overview. *International Journal of Science Education, 33*(8), 1109-1130. https://doi.org/10.1080/09500693.2010.502191

Oliva, J. M. (2019). Distintas acepciones para la idea de modelización en la enseñanza de las ciencias [Different definitions for the idea of modeling in science education]. *Enseñanza de las Ciencias, 37*(2), 5-24. https://doi.org/10.5565/rev/ensciencias.2648

Özay, E., & H. Öztaş (2003). Secondary students' interpretations of photosynthesis and plant nutrition. *Journal of Biological Education, 37*(2), 68-70.

Özgür, S. (2018). A study on young Turkish students' living thing conception. *Educational Research and Reviews, 13*(5), 150-165.

Parker, J. M., Anderson, C. W., Heidemann, M., Merrill, J., Merritt, B., Richmond, G., & Urban-Lurain, M. (2012). Exploring undergraduates' understanding of photosynthesis using diagnostic question clusters. *CBE—Life Sciences Education, 11*(1), 47-57. https://doi.org/10.1187/cbe.11-07-0054

Plomp, T. (2013). Educational design research: an introduction. In T. Plomp & N. Nieveen. (Ed.), *Educational Design Research*. SLO.

Pujol, R. M. (2003). *Didáctica de las ciencias en la educación primaria* [Science education in primary education]. Síntesis.

Psillos D., & Kariotoglou P. (2016). *Iterative desing of teaching-learning sequences*. Springer Nature.

Rasch, G. (1960). *Probabilistic models for some attainment and intelligence tests.* Denmark's Pedagogical Institute.

Reeves, T. C. (2006). Design Research from a Technology Perspective. In V. Akker, J. Gravemeijer, K. McKenney & N. Nieveen. (Ed.), *Educational Design Research*. Routledge.

Reinoso, R., & Delgado-Iglesias, J. (2020). Understanding pre-service teacher conceptual knowledge of human nutrition processes through drawings. *Journal of Baltic Science Education, 19*(6), 1008-1019. https://doi.org/10.33225/jbse/20.19.1008

Sammet, R., & Dreesmann, D. (2017). What do secondary students really learn during investigation with living animals? Parameters for effective learning with social insects. *Journal of Biological Education, 51*(1), 26-43. http://dx.doi.org/10.1080/00219266.2016.1150873

Sanmartí, N. (2000). El diseño de unidades didácticas [The design of teaching sequences]. In F. J. Perales & P. Cañal. (Ed.), *Didáctica de las Ciencias Experimentales* (pp. 239-276). Marfil.

Schussler, E. E., & Olzak, L. A. (2008). It's not easy being green: student recall of plant and animal images. *Journal of Biological Education, 42*(3), 112-119. https://doi.org/10.1080/00219266.2008.9656123

Shepardson, D. P., Wee, B., Priddy, M., & Harbor, J. (2007). Students' mental models of the environment. *Journal of Research in Science Teaching, 44*(2), 327-348.

Simsekli, Y. (2018). Examination of conceptual structures of science preservice teachers about metabolic events and energy forms in the cell. *European Journal of Science and Mathematics Education, 6*(4), 129-136. https://doi.org/10.30935/scimath/9528

Soulios, I., & Psillos, D. (2016). Enhancing student teachers' epistemological beliefs about models and conceptual understanding through a model-based inquiry process. *International Journal of Science and Mathematics Education, 38*(7), 1212-1233. http://dx.doi.org/10.1080/09500693.2016.1186304

Svoboda, J., & Passmore, C. (2013). The strategies of modeling in biology education. *Science and Education, 22*, 119-142.

Tanner, K., & Allen, D. (2002). Approaches to cell biology teaching: a primer on standards. *Cell Biology Education, 1*, 95-100.

Tekkaya, C., Capa, Y., & Yilmaz, O. (2000). Prospective teachers' misconceptions concerning general biology concepts. *Hacettepe University Journal of Education*, *18*, 140-147.

Tetz, V. V., & Tetz, G. V. (2020). A new biological definition of life. *Biomolecular Concepts, 11*, 1-6. https://doi.org/10.1515/bmc-2020-0001

Torres-Porras, J., & Alcántara-Manzanares, J. (2019). Are plants living beings? Biases in the interpretation of landscape features by pre-service teachers. *Journal of Biological Education, 55*(2), 128-138. https://doi.org/10.1080/00219266.2019.1667405

Venville, G. (2004). Young children learning about living things: a case study of conceptual change from ontological and social perspectives. *Journal of Research in Science Teaching, 41*(5), 449-480.

Wright, B. D. (2003). Rack and stack: time 1 vs time 2 or pre-test vs post pest. *Rasch Measurement Transcations, 17*(1), 905-906. *https://www.rasch.org/rmt/rmt171a.htm*

Appendix I

Questionnaire on living beings

Personal details

Name: Age:

Sex: female/male Academic year:

Degree: Type of Baccalaureate studied:

What are living beings?

Part one

1.- Explain what it means when something is living.

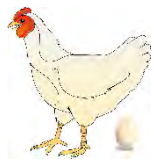
2.- What are the characteristics that define a living being and differentiate it from a non-living being?

3.- Indicate the kingdoms in which living beings are classified, naming an example for each one.

Part two

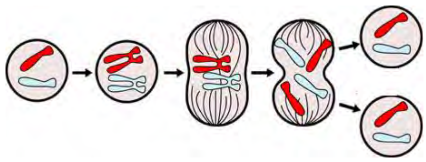
4.- Explain in detail if there is a connection in each illustration with the function of reproduction, justifying your answer.

A. Growing plant



B. Hen laying an egg

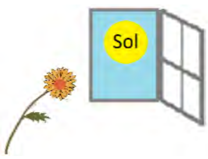
C. Mulatto child



D. Cell containing chromosomes

5.- What do you understand by the function of reproduction in living beings? Provide a detailed answer.

6.- Explain in detail if there is a connection in each illustration with the function of interaction, justifying your answer.



A. Plant growing towards the light

B. Pulling one's hand away from the fire

C. Bird chirping

D. Two friends talking

7.- What do you understand by the function of interaction in living beings? Provide a detailed answer.

8.- Explain in detail if there is a connection in each illustration with the function of nutrition, justifying your answer.

A. Woman breathing

B. Tree in the sun

C. Man doing sport

D. Person with drip

9.- What do you understand by the function of nutrition in living organisms? Provide a detailed answer.