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A Study of the Usefulness of Physical Models and Digital Models for Teaching Science to Prospective Primary School Teachers

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Abstract: This study focuses on the impact of the use of teaching resources on future teachers in different formats, physical and digital. We worked with a single task dealing with nutrition in humans with two groups of students, but one group worked with a version of the task that used physical resources, and the other group used digital resources as tools. Analyzing the work carried out and the answers given by the future teachers, it has been possible to observe the advantage of using digital resources over physical ones, although it did not generate significant differences between the two groups of participating students. This study shows how convenient it is to increase the use of digital models because of their lower cost, greater availability and ease of use. In short, they argue that the teaching of scientific knowledge should be complemented by the use of resources and models that facilitate learning, regardless of the format of the resource used.

Keywords: digital education; educational resources; initial teacher training; primary education; teaching activities

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1. Introduction

In recent years, different approaches to science education have been developed around the development of scientific practices based on modeling [1,2]. Thus, modeling can be understood as the process of developing, evaluating and refining scientific explanations of natural phenomena [3]; besides that, inquiry is the process of designing and carrying out experiments and analyzing and interpreting data [4], while argumentation consists of communicating one's ideas and interpretations of results in order to persuade others of their validity [5].

Within these scientific practices, teaching by modeling, or more specifically, teaching–learning approaches based on models, are currently one of the most popular lines of work in science teaching [1]. The aim, in essence, was to construct representations of reality (models) with the aim of explaining it and making predictions, which are evaluated and readjusted when put into practice [6]. A model would be, in this context, a partial representation that shows certain aspects of the phenomenon with the specific purpose of developing explanations about it [7].

The use of modeling in science education allows, on the one hand, contrasting initial expressions of previously acquired models with comparisons or scientific perspectives that lead to the evaluation and revision of previous models [8], and on the other hand, coordinating various modes of representation that facilitate students' construction of their knowledge based on such diverse pillars [9]. Moreover, students' use of different visual representations allows them to identify elements or parts, generate meanings that promote greater understanding and consequently develop deeper learning of the represented content [10].

Hence, some studies consider that modeling competence should be understood as the set of knowledge, skills, abilities and epistemic values necessary to carry out the task of modeling in its broadest dimension. These models used in the learning of science in schools, in addition to working with them, allow for the development of other capacities, placing value on their usefulness, their approximate nature and the ease with which they can be adapted to the content being worked on [11].

Schwarz et al. have delved into the tasks to be carried out in modeling practice, from less to more complex: (a) building models consistent with admissible evidence and theories on how to illustrate, explain and predict phenomena; (b) using models to illustrate, explain and predict phenomena; (c) comparing and evaluating the ability of different models both to adequately represent and capture patterns in phenomena and to predict new ones; and (d) revising models in ways that increase their explanatory or predictive potential, considering additional evidence or new aspects in the same or similar phenomena [6].

However, the lack of familiarity among students with this educational practice requires teachers to provide more and more precise didactic support to help students when starting modeling [12]. The teachers should be participating in the process of creating and testing models, and they should be making the need for a well-sequenced initiation of such tasks [13].

There are different modes of representation for modeling in science education, such as drawings, diagrams, models, metaphors, analogies, and simulations [11]. The use of these models helps the student to move away from memorizing the theories, laws and hypotheses that appear in the curriculum and helps students to better understand science and, in turn, better understand the world around them. The flow of activities involved in the model should be recognizable to students; it should be familiar and not too complex, as this will not lead to monotony and boredom [14].

In this context, Gómez Galindo (2007) [15] highlights the value of models as mediating representations between the generation of argumentative thinking with previous experiences and the new ones presented by manipulating the model. The use of models is widely implemented in different educational stages, from Primary Education [16] to higher education [17]. Even in initial teacher training [18], different didactic instruments are used, as it is necessary to train future Primary school teachers in didactic and scientific skills [19].

The use of both DM and PM offers a number of advantages and disadvantages, which are summarized in Table 1. These authors highlight the ease of access to both models, and the disadvantages are due, in the case of DM, to the availability of access, while in the case of PM, they refer to the use of the models as such.

Table 1. Summary of advantages and disadvantages of using DM and PM.

	Reference	Advantages	Disadvantages
DM	Murgitroyd, Marduska, Gonzalez and Watson [20]	Can enhance learning of complex structures. Useful in medical practice simulations. Improve understanding of complex anatomical structures and relationships.	They require reliable and affordable technology.
	Deng, Zhou, Xiao, Zhao, He and Chen [21]	Learning outcomes are improved. Students can access the simulation remotely. Provides accurate anatomy information.	The simulation does not provide a tactile sensation of the hardness, weight or flexibility of the organs. Some small parts do not have sufficient resolution.
	García-Bonete, Jensen and Katona [22]	Better realism (VR). Unique experience (VR). Experience can be shared with others (AR). Only smartphone is needed (AR).	Unintuitive use of controls (VR). Cannot be shown to others (VR). No different from viewing on a computer screen (AR). Unintuitive controls (AR). Unrealistic simulation (AR).
	Arslan, Kofoglu and Dargut [23]	Facilitates understanding with 3D models. Increases student motivation. Increases student success. Easily accessible by smartphone.	It does not allow the whole of a subject to be covered. More content needs to be developed, especially basic biology.

Table 1. *Cont.*

	Reference	Advantages	Disadvantages
PM	Fančovičova and Prokop [24]	PM, by simplifying anatomy and differentiating by color, facilitates learning and retention.	PM may be perceived as less stimulating than real specimens.
	Yammine and Violato [25]	Promotes knowledge in general. Promotes the acquisition of spatial knowledge. Facilitates long-term knowledge retention. Easy accessibility.	Not described in the study.
	García and Mateos [26]	Making PM promotes visual literacy in human anatomy.	Not described in the study.
	Sánchez-Ortiz, Sterp and Hernández-Muñoz [27]	They gave students access to virtual dissections of different models of living beings.	Teachers may perceive them as obsolete objects in favor of other resources and devices.

The situation experienced in the last two academic years by COVID-19 has made it necessary to change many aspects related to the organization of both teaching and learning processes, leading to adaptations both in the management and dynamics of classes, in the planning of the different subjects, and in teaching resources [28]. Initial teacher training has also been affected by this situation, which has led to new scenarios (blended learning, outdoor classrooms, . . .) that favor science learning [29]. It was necessary to remember that during the pandemic period, education had to take measures such as social distancing, activities in very small groups and in the open air, and even not exchanging material between students or not using the same material.

2. AIMS

The purpose of this work was to study different adaptations in the teaching–learning of the human body through the use of different types of models in the initial training of future Primary school teachers. Specifically, our research focuses on the following objectives:

1. To diagnose the previous use of models in biology among future teachers of Primary Education in their Primary, Secondary and University studies;
2. To carry out a comparative study of the educational performance of future Primary Education teachers in a specific biology problem situation (transport of oxygen inside the human body), between the use of physical and digital models;
3. To analyze the future Primary School teachers' assessment of the educational use of the physical or digital models used.

3. Materials and Methods

3.1. Context and Participants

The present work was developed within the subject "Teaching and Learning of the Natural Environment I", during the academic year 2020/2021. This subject was the second of the three subjects of Didactics of Experimental Sciences of the Degree in Primary Education at the University of Murcia, with a total of 6 ECTS (European Credit Transfer System) credits in the second year. An incidental sample of 140 students from two of the groups was used (G1, 76, and G2, 64, respectively), which had the same teaching staff in the subject in which the work was carried out and in the same semester. The total population of students enrolled in this subject was 360, so the sampling error was 6.4% (with a confidence level of 95%). The profile of these students was similar to that of previous years (72.1% female, average age 21 years, and the most frequent subject in the Baccalaureate, Social Sciences). Additionally, in particular, certain deficiencies that are repeated in their general didactic knowledge existed: lack of mastery of the curriculum and difficulties in classroom management [30].

3.2. Student Work

To achieve the aims set out in this study, a work sequence was established in which the students involved start with a theoretical approach to the knowledge addressed in two theoretical sessions lasting 2 h each. Subsequently, they carry out a practical session (2 h) in which they put into practice the knowledge acquired in the previous work phase through the work proposed by the teachers in a practice script. Finally, the students completed an online self-assessment questionnaire proposed by the teachers of the subject to check the knowledge acquired during this work proposal on the human body and health, the first of the three blocks of content of the subject.

The participating students proposed a group practice, in which they had to solve a series of questions related to the subject of the functioning of the human body through the use of models, following a work script (Figure 1).

According to a general perspective on nutrition, explain the route taken by an oxygen molecule that enters the body and has to reach the muscles in your legs that demand a lot of oxygen because you are running. You should write in order the names of the organs through which the molecule passes and clearly indicate to which system each organ belongs. In addition, to help your explanation, make a schematic drawing on a silhouette of the human body like the one attached.

Figure 1. Work script to be carried out by the students.

After this practical group work, the students were asked to answer individually a specific question that allowed the students to consolidate the contents previously worked on in the theoretical and practical sessions. This question was as follows: *According to a general perspective on nutrition, explain the route taken by an oxygen molecule that enters the body and has to reach the muscles in your legs that demand a lot of oxygen because you are running. You should write in order the names of the organs through which the molecule passes and clearly indicate to which system each organ belongs. In addition, to help your explanation, make a schematic drawing on a silhouette of the human body like the one attached*. In order to evaluate the students' answers, an evaluation rubric was established (Table 2), which allowed for a quantitative analysis of the answers given.

The mock-ups that were proposed to the students for the work with the working script were of two different types, physical and digital (Figure 2). The first group (PM, hereafter) used the physical plastic resin mock-ups representing a human torso, which was detachable from head to intestines. These classical mock-ups were used in an outdoor environment and with a protocol of cleanliness and interpersonal distance, to prevent the spread of the SARS-CoV-2 virus. The second group (DM) used the digital models of the Organs 3D app, a free-to-download mobile phone application that provides a three-dimensional view of the different apparatuses and organs of the human body (https://apps.apple.com/es/app/órganos-3d-anatom%C3%ADa/id947265034) (accessed on 10 December 2022).

Table 2. Rubric for assessing students' work.

Issue	Type of Reply	Assessment of the Reply
Route	It is able to determine the path taken by the oxygen molecule through the human body.	If the answer is correct, it is given a score of 2; if there is an error or inaccuracy, it is given a score of 1; and if it is completely wrong, it is given a score of 0.
Order organs	In the path of oxygen through the human body, correctly establish the sequence of the organs through which the molecule travels.	If the answer is correct, it is given a score of 2; if there is an error or inaccuracy, it is given a score of 1; and if it is completely wrong, it is given a score of 0.

Table 2. *Cont.*

Issue	Type of Reply	Assessment of the Reply
Order Body systems	The sequence of systems and apparatus through which the oxygen molecule moves is correctly established.	If the answer is correct, it is given a score of 2; if there is an error or inaccuracy, it is given a score of 1; and if it is completely wrong, it is given a score of 0.
Use Image support	Uses a visual resource to illustrate their explanation of the questioned issues.	Yes (1) or No (0).
Correct image	The figure used is properly organized (sequence of organs, sequence of systems, arrangement with reference to the body).	If the reply is correct, it is given a score of 2; if there is an error or inaccuracy, it is given a score of 1; and if it is completely wrong, it is given a score of 0.
Qualification	Taking into account the different sections above and the work performed by the student, an overall assessment of the answer given by the student is given.	Rating from 1 to 4, with 1 being negative and 4 positive. In addition, a score of 2 or more considered the response to be correct, while scores of less than 2 were considered not correct.

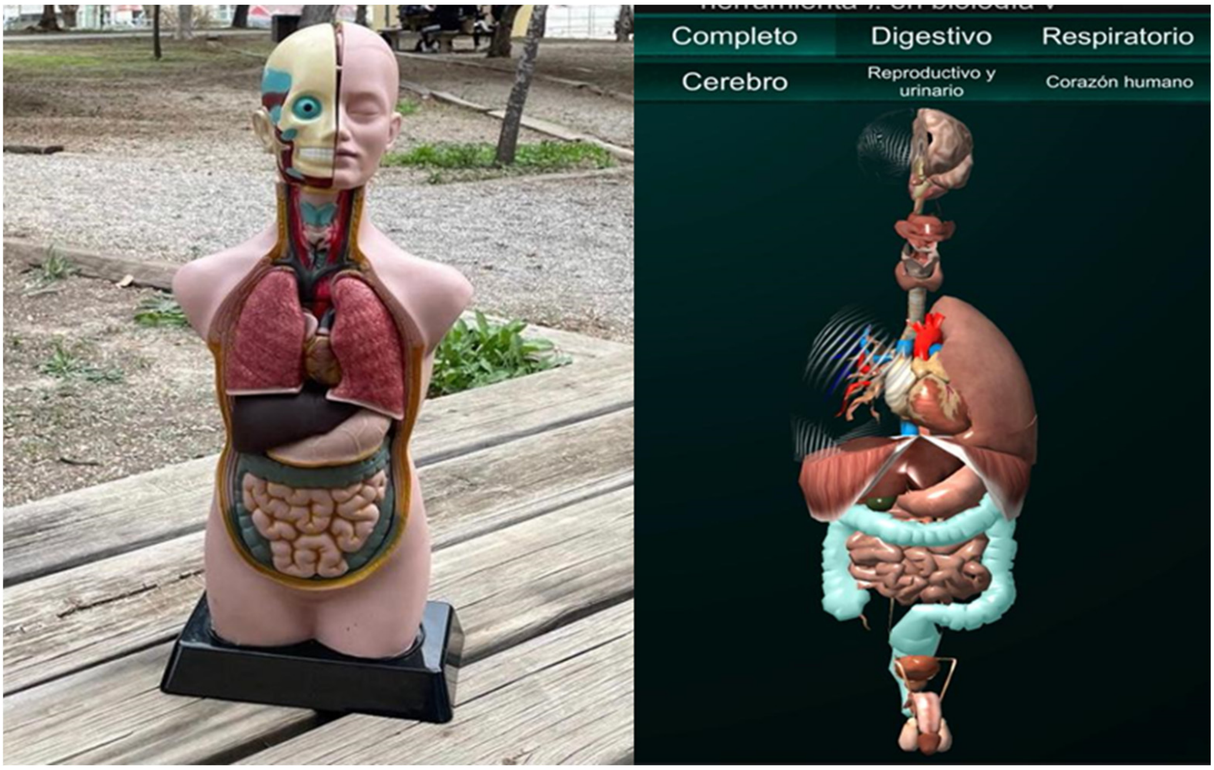

Figure 2. Physical (**left**) and digital (**right**) mock-ups used by students.

3.3. Post-Practical Work Questionnaire

In order to analyze the impact of the use of different types of models, students were provided with a questionnaire through the Google Forms platform, which can be consulted at https://forms.gle/XFWyVb6BytUUtfkr8. This questionnaire was calibrated and validated by Robles et al. (2022) [31]. This questionnaire was composed of two blocks of questions, the first of which consisted of questions to determine the profile of the students and their previous interaction with models.

The second block of questions was an evaluation using a Likert scale from 1 to 4, 1 being totally disagree and 4 being totally agree, of 7 different items, aimed at finding out the evaluation of the use of the models in the development of the practical exercise. The items that the students were asked to evaluate are shown in Table 3 below.

Table 3. Items on the evaluation of the use of the models.

Target	Item
Motivation	I found the use of the model very motivating.
Lack of knowledge	Before using the anatomical model, I did not know what we look like inside.
Arrangement	The model has helped me to better understand the internal arrangement of the organs.
Visualization	Visualisation of scientific models is very important in science education.
Understanding	The internal structure of the human being is better understood through verbal explanations, either oral or written, than through the use of models
Use resource	The use of models in primary education can be a useful resource for teaching about the human body.
Adequacy	Found the representation of the organs and systems in the model to be adequate.

Once the responses had been collected both from the work performed by the students and from the *Google Forms* questionnaires, the data were tabulated and pre-processed using *Microsoft Excel* software. Subsequently, the statistical software *JAMOVI* was used to analyze the data and determine the possible differences in the responses, as well as their level of significance.

4. Results and Discussion

4.1. Previous Use of Models by Future Primary School Teachers

Before carrying out the teaching proposal that was designed, the students were asked about their use of physical or digital models at other school stages (aim 1). The results indicate that, throughout their educational career, 8.4% of the sample analyzed do not remember having had any contact with physical models; this percentage increases to 34.3% with digital models (Figure 3). With regard to the educational stage in which they carried out an activity in which they used models, we found that, in the case of physical models, their use was similar in both stages, both in Primary Education (54.5%) and in Secondary Education (53.1%); however, with digital models, their use was predominantly in Secondary Education (44.8%), compared to their use in Primary Education (16.1%) or in Higher Education (16.8%).

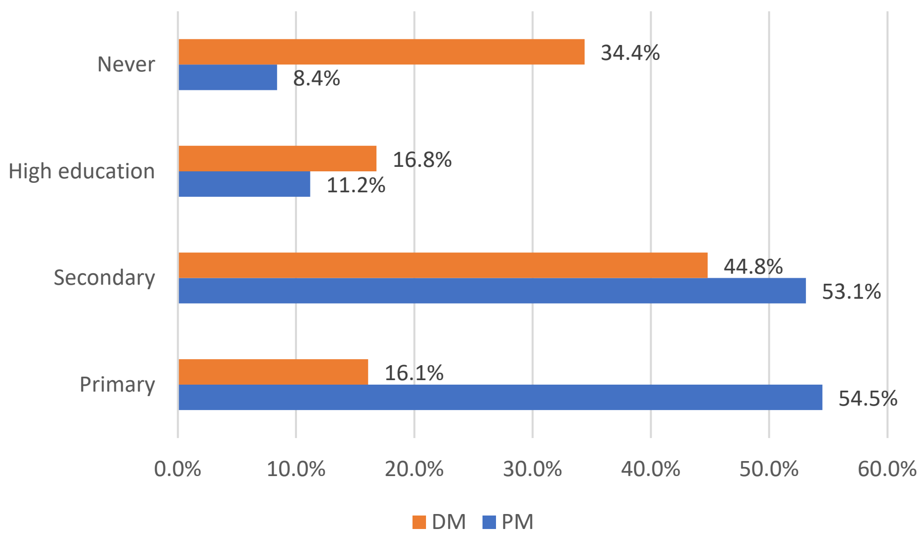

Figure 3. Students' prior contact with physical and digital models of the human body.

4.2. Work Carried out by the Students

For the assessment of the students' responses to the work proposal presented to them (aim 2), the evaluation rubric described above was used (Table 3). Following the items and evaluations described, Table 4 shows the mean values and standard deviation of each of the sections, taking into account the total participating sample (All) and differentiating between the PM group and the DM group.

Table 4. Mean values, standard deviation, and comparison of means with the Mann–Whitney U test of the different sections assessed in the replies submitted by the students.

Group	Route		Order Organs		Order Body Systems		Correct Image		Qualification	
	M	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**
PM	1.55	0.59	1.53	0.61	1.52	0.61	1.43	0.69	2.64	0.99
DM	1.67	0.58	1.64	0.59	1.66	0.59	1.56	0.52	2.68	0.85
ALL	1.60	0.59	1.58	0.60	1.58	0.60	1.48	0.62	2.55	0.93
Mann–Whitney U	2155		2218		2152		2280		2441	
p-value	0.123		0.226		0.125		0.386		0.923	
Significant difference	No		No		No		No		No	

In the different items, it can be observed that the scores obtained are always above the mean values with which each section was evaluated. In this line, the DM group always obtained slightly higher values than the PM group. In this sense, in the Qualification section, 77.9% of all students consider themselves to have given a correct answer, i.e., scores in this section equal to or higher than 2 (PM = 2.6; DM = 2.6 and All = 2.6). By groups, the DM shows 79.7% of correct replies, while the PM decreases to 76.3% of correct answers. Most of the incorrect answers are due to the fact that they made a schematic answer or did not present an answer as such but did present a supporting image. However, only 4 of the 140 students who submitted their work did not use a supporting image for their explanations (three from the PM and one from the DM).

Similarly, to check whether the mean values obtained for each item in each of the groups show a significant difference, the Mann–Whitney U test was applied, since a normal distribution of the data cannot be assumed. The results of this test (Table 3) indicate that, although the means are different in both groups analyzed, the difference was not significant. This seems to indicate that the learning outcomes achieved do not depend significantly on the type of educational resource used (analog or digital model).

4.3. Difficulties/Errors Identified

In their work, the students showed certain errors or difficulties with basic aspects such as, on the one hand, errors referring to the basic anatomy of the human body, and on the other hand, errors referring to the basic anatomy of the human body. Additionally, in another section, errors included those referring to the differentiation between cellular respiration and gas exchange.

a. Knowledge of the basic anatomy and physiology of the respiratory system.

From the answers given by the students, it was noteworthy that one of the most common errors identified by our analysis was not recognizing the mouth as one of the possible ways for air to enter the human body (student 26: "*oxygen enters our body through the nostrils*" (in Spanish: "*el oxígeno entra en nuestro cuerpo a través de las fosas nasales*")) or in their images presented, although they are aware of the oral cavity, they do not point it out, focusing only on the respiratory apparatus composed of nostrils, pharynx, larynx, trachea, bronchi, bronchioles and pulmonary alveoli (Figure 4), and neither do they point out parts such as the diaphragm or the epiglottis, essential structures for breathing.

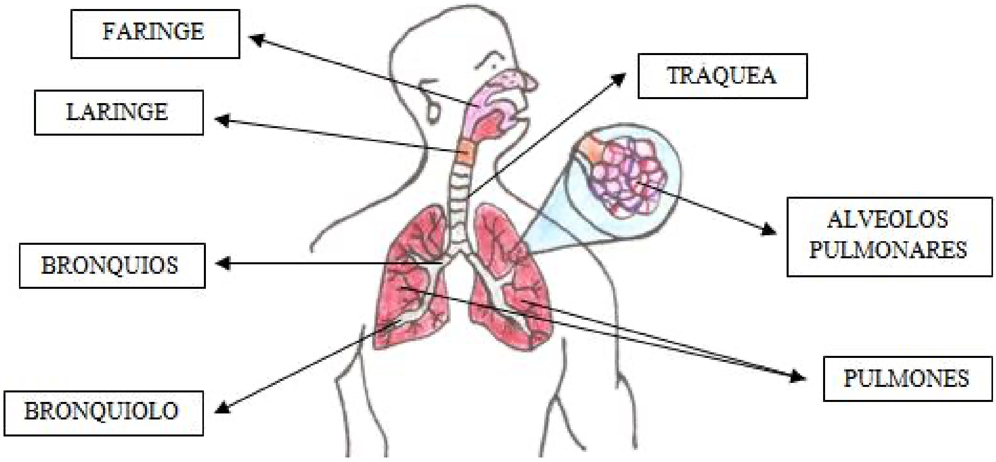

Figure 4. Example of supporting image used by students (student 44).

To a lesser extent, other errors students made were not pointing out the diaphragm in their supporting images, or including the tonsils in their explanations, but not pointing them out in their illustrations (for example, student 15: " ... *passes into the pharynx and then reaches the tonsils, which act by destroying pathogenic organisms*" (in Spanish: " ... *pasa a la faringe y luego llega a las amígdalas, que actúan destruyendo los organismos patógenos*")). Additionally, at the level of the description of the circulatory system, among the main errors that students present, they reduce this system to the heart and the main blood vessels, without explicitly showing the connection between the circulatory apparatus and the cells (an aspect that was repeatedly identified among students of different educational levels [23]). As can be seen in the example of student 63: "*Once the oxygen molecule has reached the pulmonary alveoli, it passes through the arteries that carry the blood from the heart to the rest of the body and is directed towards the heart*" (in Spanish: "*Una vez que la molécula de oxígeno ha llegado a los alvéolos pulmonares, atraviesa las arterias que llevan la sangre del corazón al resto del cuerpo y se dirige hacia el corazón*").

b. Relationship of the respiratory apparatus to cellular respiration

Finally, the students, supported by the use of physical or digital models, depending on the group, had to solve the task in which they were asked to "*Explain the route taken by an oxygen molecule that has just entered the body and that has to reach the muscles of your legs that demand a lot of oxygen because you are running*". In this way, the students had to determine the route and process for the oxygen molecule to reach the muscles of their legs and be able to make use of this molecule. We found (in accordance with what has been pointed out in works such as [24]) that few students finish the route in the mitochondria, an organelle where the process of cellular respiration takes place, taking advantage of oxygen as a necessary element for obtaining the necessary energy so that in this case the muscle can carry out its work. As an example, we find the answer given by student 48: "*Cellular respiration takes place in the mitochondria, where oxygen participates in the chemical reaction that allows ATP (energy) to be obtained*" (in Spanish: "*La respiración celular tiene lugar en las mitocondrias, donde el oxígeno participa en la reacción química que permite obtener ATP (energía)*"); this type of answer is in the minority, as the vast majority of answers ended when the oxygen molecule was in the bloodstream.

4.4. Evaluation after Implementation of the Proposal

With reference to the evaluation of the use of the models by the students after carrying out the didactic sequence designed (aim 3), this was presented in summary form in Table 5, distinguishing for each item the two working groups and the total number of students (the different items used for the evaluation of the use of the models and their description are shown in Table 3). When evaluating each item, the prospective primary school teachers had to rate from 1, strongly disagree, to 4, strongly agree (1—strongly disagree, 2—agree, 3—agree, 4—strongly agree).

Table 5. Results of the evaluation after carrying out the proposed teaching sequence.

	Group	N	m *	Quartiles			M *	Mann–Whitney U	p-Value	Significant Difference
				Q1	Q2	Q3				
Motivation	**PM**	**77**	**3**	**3**	**3**	**4**	3.27	2399	0.548	No
	DM	64	3	3	3	4	3.18			
Lack of knowledge	PM	77	1	1	1	2	1.50	1712	<0.001	Yes
	DM	64	2	1	2	2	2.00			
Arrangement	PM	77	3	3	3	4	3.21	1943	0.008	Yes
	DM	64	4	3	4	4	3.52			
Visualization	PM	77	4	3	4	4	3.69	2499	0.853	No
	DM	64	4	3	4	4	3.69			
Comprehension	PM	77	2	1	2	2	1.77	2185	0.118	No
	DM	64	1	1	1	2	1.60			
Use resource	PM	77	4	4	4	4	3.86	2480	0.691	No
	DM	64	4	4	4	4	3.89			
Adequacy	PM	77	4	3	4	4	3.60	2331	0.337	No
	DM	64	4	3	4	4	3.49			

* M = mean; m = median.

As can be seen, the item with the highest score, both in the different quartiles and in terms of the median, was related to Use resource (the use of models in Primary Education can be a useful resource for teaching the human body). In this sense, prospective Primary school teachers give the same score for physical models (4) as for digital models (4). This result was in line with other studies [32–34], which state that the use of modeling in its different versions helps students to approach the different scientific knowledge

For the items Visualization (the visualization of scientific models was very important in science teaching) and Adequacy (I found the representation of the organs and systems in the model to be adequate), the median values are equally high (4), with the same value being repeated for both the group that used physical models and the group that used digital models.

As for the item Motivation (I found using the model very motivating), both groups behave in a similar way, with the median reaching a value of 3, which can be interpreted as high motivation, whether the resource used was the physical model or the digital model.

Moreover, the students disagree with the statement that verbal explanations of the internal structure of the human being are better than the use of models, as the scores obtained in the item Understanding (the internal structure of the human being was better understood through verbal explanations, whether oral or written, than through the use of models) attest to this. In the group that used the physical models, the median value was 2, while in the group that worked with the digital models, the median value decreased to 1, and the quartiles behaved in the same way.

To determine whether the differences in the responses between the groups were significant, the Mann–Whitney U test was applied, since it was impossible to affirm a normal distribution of the data (Table 4). In all but two cases, the differences were found to be non-significant. Significant differences are found in the items Lack of knowledge and Arrangement. In the case of the item Lack of knowledge (Before using the anatomical model I did not know what we are like inside), the students in the PM group show a higher degree of disagreement with the proposed statement, which seems to indicate that even before using the analog model, they considered themselves to be knowledgeable about the internal body structure of the human being. In the case of the item Arrangement

(The model has helped me to better understand the internal disposition of the organs) the students of the DM group are the ones who showed a higher degree of agreement with the statement, so it seems that the way the DM group perceived the models helped them understand the structure and internal disposition of the organs of the human body to a greater extent than the PM group.

5. Conclusions

The research has shown that the university students in our study report greater use of physical models during their time as Primary school students, while both physical and digital models have been used with them at the following educational levels (Secondary school and Higher Education) in a similar way (aim 1). This result seems to show a greater preference among Primary school teachers for the physical model, probably because it was closer to a real situation and therefore more easily understood by pupils at this level; however, at Secondary school or university, it was possible that pupils have less difficulty in using digital models.

In the analysis of the results obtained in the implementation of this study (aim 2), it was found that, despite not finding significant differences in our work between the two groups investigated, there was a slightly better result in favor of the use of digital models compared to physical ones, which suggests the educational interest, in the training of future teachers, of using the former as they are cheaper (usually free applications) and more readily available, as they only require any digital device and are easier to use, allowing pupils to use them even outside the school environment.

Furthermore, in the evaluation of the work proposal proposed to the students (aim 3), they rated the aspects of visualization and use of the resource very positively, considering the use of the models, both physical and digital, to be useful and of great help, these aspects being the best rated and without significant differences between the two groups. However, significant differences were found between the two groups in the aspects of lack of knowledge and willingness, reaffirming that the use of the models provided them with the necessary help to understand the knowledge being addressed. Additionally, it was appreciated that digital models helped to a greater extent to better understand the internal arrangement of human organs.

In addition, it was found that current Primary school teachers in training, although they belong to the so-called digital natives' generation, focused their attention on explanatory presentations rather than the use of resources, possibly because the format of the resource itself is not so important to them.

As a significant result and the pedagogical impact of this analysis, we can see the need to continue popularizing and deepening methods based on the use of both analog and digital models in order to provide future teachers with better scientific and pedagogical training. We know that future teachers who are trained to use different scientific models will have a better understanding of them and will thus be able to provide a better science teaching and learning experience for their future students.

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