Using multiple strategies in deepening the understanding of the digestive system

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ABSTRACT

The digestive system (DS) is a fundamental topic in biological science teaching. However, the literature indicates that students have difficulties in its learning. In the present work, we focus on how early childhood Pre-Service Teachers (PSTs) develop their understanding of the DS regarding the CMP (Components-Mechanisms-Phenomena) framework of systems thinking. A teaching sequence was designed, implemented and iteratively improved over the course of three years, and in Year 3 included the construction of a physical model and the design and performance of a role-play. Data collection was performed using individual questionnaires before and after participating in the practical activities. The physical models and the role-plays were also analysed. The results show that participation in the sequence improved the understanding of the DS in all dimensions of systems thinking, especially in Year 3. The construction of physical models mainly fostered learning Components and the role-play seemed to facilitate a deeper understanding of Mechanisms. It is concluded that the combined use of both modes of representation constitutes a valuable strategy for science education.

Keywords: digestive system; science teaching; physical model; role-play; pre-service teachers

Introduction

How do teachers facilitate learning? According to Osborne and Wittrock (1985), teaching is concerned not only with imparting but also with developing skills and strategies for subsequent learning. One tool for teachers to help the students to construct their own knowledge networks is the generative learning strategy. This strategy implies that learning involves the creation and refinement of individual mental constructions about the world (Grabowski 1996; Wittrock 1974). Hands-on activities have been pointed out as useful for promoting interest and conceptual knowledge when they are accompanied by reflection and discussion (Weaver 1998) compared to giving information. Nevertheless the effectiveness can be dependent on the topic, for example dependent on the level of abstraction of the concept (Kiroglu, Turk, and Erdogan 2021). The human body is one of the science topics of great interest in education. It can be defined as 'an entity consisting of a large number of structures, at different levels of organisation (micro and macro), in which various processes occur' (Snapir et al. 2017, 2095); and thus, not only must the structures in the system be studied, but also the mechanisms of the interactions between them and the outcomes of those interactions (Bechtel and Abrahamsen 2005; Goldstone and Wilensky 2008). In this sense, Hmelo-Silver et al. (2017) created the Components-Mechanisms-Phenomena (CMP) framework to analyse systems understanding. This framework provides a representation of the whole system, including the structures (Components) of the system, the processes and interactions (Mechanisms) that occur between them, and the output of the processes or mechanisms within a system (Phenomena).

The digestive system (DS) is central to human nutrition, health and well-being and knowledge of it favours a global understanding of the human body (Boland 2016; Hall 2016). However, the literature indicates that students have erroneous ideas about the DS. The most common are anatomical (Components) misconceptions such as the following: (1) viewing the DS simply as a tube that begins in the mouth and leads to the stomach, where most digestion and nutrient absorption occurs (Garcia-Barros, Martínez-Losada, and Garrido 2011; Talamoni, Carolina, and de Andrade 2017; Banet 2008), (2) including compartments and structures that are not part of the system (e. g. the larynx or the lungs) (Aydın and Keleş 2018; Granklint Enochson et al. 2015; Dempster and Stears 2014; Banet 2008), (3) confusing excretory and digestive organs (Aydın 2016), and (4) others related to the position, shape, size and colour of various digestive organs (Mohapatra and Roy 2018).

Other studies indicate that students in general know the organs in the human body but they fail to situate them in systems, to build relationships between them and to fully understand their functions (Mechanisms) (Cuthbert 2000; Reiss et al. 2002; Özsevgeç 2007; Aydın 2016;). Also, Teixeira (2000) suggested that particular attention should be given to the concept of transformation (Mechanisms), especially chemical transformation, and to understanding the digestive system as a system related to others (Mechanisms). Moreover, Granklint Enochson et al. (2015) described that students found it difficult to integrate the functions of different systems when they were asked to transfer their knowledge from the digestive and circulatory systems (sandwich scenario) to a new scenario (painkiller).

However, fewer studies aim to assess the effectiveness of teaching proposals that may promote conceptual change on this topic. For that purpose, different strategies such as experiments simulating processes (Bahamonde and Gómez Galindo 2016; Mattos Feijó, de Andrade and Coutinho-Silva, 2020), virtual strategies (Šorgo, Hajdinjak, and Briški 2008; Vilkonienė 2009) and physical models (Bahamonde and Gómez Galindo 2016; García and Mateos 2018) have been proposed. The use of a dramatic simulation was also proposed (Benarroch 2008) but it was more focused on nutrition than on the DS. In fact, only the small intestine was represented in that study.

This work addresses the use of physical models and drama for modelling the DS, as previous research on other topics (e.g. Braund and Ahmed 2019; García and Mateos 2018; Gómez 2008; McSharry and Jones 2000; Ogan-Bekiroglu 2007; Padalkar and Ramadas 2011; Walan 2020) has shown that they facilitate the learning of scientific models and are suitable for teaching in early childhood.We selected early childhood Pre-Service Teachers (PSTs) as subjects because they need to learn science concepts in ways that are consistent with how they will eventually be asked to teach (Zembal-Saul 2009). Concretely, we focus on how PSTs develop their understanding about the DS when they participate in a sequence of activities that includes the construction of physical models and the design and performance of a role-play. In contrast to previous studies, this study focuses on the understanding of the DS in terms of the various dimensions of systems thinking, and addresses the contribution of the different activities to these dimensions. Hence, the research questions are:

(1) How do early childhood PSTs develop understanding about the DS, regarding the CMP framework of systems thinking?
(2) How do the construction of a physical model and the design and performance of a role-play facilitate PSTs' learning about the DS?

The Use of Physical Models in Science Education

In the modelling context, a representation is a concrete external expression of a model, having a given intention: communicative, cognitive or operational (Adúriz-Bravo, Gómez, Márquez, and Sanmartí 2005). Following Gilbert (2005), models (which can be mental, expressed, scientific, curricular, etc.) are usually represented in five modes, which can be combined or used one after another, and which constitute a spatial language: (1) the visual mode is two-dimensional, and consists of diagrams, graphs, as well as representations made by computers or virtual modes; (2) the concrete or material mode is 3D and, thus, made of materials; (3) the symbolic mode consists of symbols, formulas, equations and other mathematical expressions; (4) the verbal mode can be spoken or written; and (5) the gestural mode consists of moving the modeller's body or its parts. Today computer simulations are popular in science education, especially at micro- and nano-scales (Schönborn, Höst, and Lundin Palmerius 2016). A rapidly growing literature shows that computer simulations promote science content knowledge, develop process skills and facilitate conceptual change (see the review by Smetana and Bell 2012). Comparisons between hands-on physical models and computer simulations are frequent in the literature; as an example, Kiroglu et al. (2021) advocated for the physical models for learning about the phases of the Moon.

Three-dimensional models are extensively used in model-based learning, where, interestingly, they function as mediators in the construction of knowledge; that is, they mediate between world phenomena and theoretical models (Adúriz-Bravo et al. 2005; Oh and Oh 2011). In addition, one may actively intervene on the 3D model through thought, action and discourse, and, therefore, influence the modelling process.

Although resorting to modelling is not common practice in the science classroom (Khan 2011), and usually teachers may simply present the model to be learned - without giving the students the opportunity to build or revise it - (Torres and Vasconcelos 2016), modelling using physical models is well-known in the literature to prompt learning. Benefits encompass learning *of* science, learning of *how to do* science and learning *about* science. These are common modelling achievements (Justi and Gilbert 2002) and they also enhance other aspects such as spatial abilities (King 2008; Ferk et al. 2003).

Regarding the learning *of* science, physical model-based modelling promotes not only the learning of the elements and the structure where they are located, but also the related relationships and processes (Steer et al. 2005; García and Mateos 2018); that is, they link structure to processes, a common difficulty in, for example, the understanding of nutrition or plate tectonics. Interestingly, Gómez (2008) found that physical models specifically contributed to the learning process, facilitating students to build the model of human senses. Indeed, students added properties of the elements of the model that were previously ignored in other types of representations.

As mentioned above, also *how to do* science seems to be an outcome of modelling using physical models; for instance, Murcia and Crespo-Blanc (2008) pointed out that modelling folds and faults with physical models involved students becoming familiar with research techniques used by geologists. Previous studies have also indicated that the task of modelling should go together with understanding the nature of models (Henze, van Driel, and Verloop 2007) and that modelling enhances interest in science (Haugwitz and Sandmann 2010).

Among factors influencing learning, Ogan-Bekiroglu (2007) pointed out that the type of physical model and selected materials might influence the learning of moon phases and other lunar phenomena (in the sense that models should approximate reality for the targeted question). In contrast, in order to model the respiratory system, Han and Kim (2019) selected physical models that were structurally far from reality but could better represent processes. Despite this, after revising the models, students successfully connected given processes with the human respiratory system's process. Another factor facilitating learning seems to be related to having an active role, as pointed out by García and Mateos (2018). In fact, Maia and Justi (2009) noticed that students needed to make the physical models dynamic when communicating their mental models to the class. These authors also found that, throughout the modelling process, the physical models concretely contributed to the expression and communication of the students' models and to the development of the mental model itself.

Although building physical models is typically set up as collaborative work (see Haugwitz and Sandmann 2010 for advantages), individual model building with physical models has also been found to promote understanding and the development of the model, as investigated by Shen and Confrey (2007).

The Use of Drama in Science Education

According to Braund and Ahmed (2019), although there is growing interest in using drama-based activities for teaching biology and science in general, their use is under-researched. Drama-based activities in science lessons include, among others, the use of body gestures to simulate the Sun-Earth-Moon system (Padalkar and Ramadas 2011), role-plays in which students take on the role of molecules (Metcalfe et al. 1984) or parts of a cell and act out processes (Walan 2020), dramatizations of scientists´ lives such as Linnaeus (Stagg 2020), or role-plays in which socio-scientific issues are debated (Simonneaux 2001). The use of drama, theatre, gestures to teach science was the subject of a review by Ødegaard (2003). As she found, and as Dorion (2009) subsequently confirmed, the presence of dramatic activities in science lessons is higher than that reflected in the academic literature. Ødegaard (2003) also found that drama-based activities in science lessons focused on scientific concepts, on the nature of science, or on the scientific community and its social implications. She pointed out that several studies have found the use of drama for concept learning generated more enthusiasm in children than in teachers, and that 'when drama was used to create a model of a scientific concept, students developed a deeper understanding of the concept' (p.93).

More recent studies have shown the potential of this resource for learning concepts such as plant classification (Stagg 2020), parts of the cell and sound transmission (Braund and Ahmed 2019), and heat transfer (Abed 2016), as well as for improving attitudes towards plants (Stagg 2020) or towards learning science (Abed 2016). In most of the above cases, the drama activities were of the analogy role-play type (McSharry and Jones 2000), with children acting as objects or elements of a scientific theory or phenomena. The use of role-plays allows, according to McSharry and Jones (2000), for students to feel a sense of ownership as they facilitate their own learning through the creation of their own role-plays, either through improvised or scripted work. Thus, analogy-based role-plays make abstract concepts more understandable. This was also observed by Metcalfe et al. (1984), who found that, while there was no difference in factual recall between the group that had role-played the states of matter and the group that had not, there were differences in favour of the group that had role-played the states of matter when it came to formulating explanations and interpretations. According to McSharry and Jones (2000), most areas of the science curriculum can be suitable subjects for analogy role-play, and in the case of biology, they give the examples of the circulatory system, structure and function of cells, enzyme action, phagocytosis, transpiration, antibody/antigen, interaction and predation.

Given that the teacher is a key agent in making good use of this educational resource, several studies have focused on analysing how teachers use drama-based activities (e.g., Braund and Ahmed 2019) and what they think of them (McGregor 2012; Walan 2020). The feedback was positive both from teachers (McGregor 2012; Walan 2020) and from students (for example, the 5-7 year olds in McGregor's (2012) study). Nevertheless, teachers acknowledged that developing these activities involved challenges: they are time-demanding (Alrutz 2004; Walan 2020) and the teacher needs to be extremely vigilant in order to point out possible errors or misconceptions (Walan 2020), as well as to avoid students confusing the phenomenon with its analogy (Alrutz 2004). Indeed, some shortcomings in designing and implementing these activities have been noted, and the need for improved teacher training in the use of these techniques has been highlighted (Braund and Ahmed 2019).

Methods

Research Context

This is a case study with three groups of PSTs studying a Degree in Childhood Education (third-year), all teached by the same teacher. These were named as Cohort 1 (corresponding to year 2017/18), Cohort 2 (2018/19) and Cohort 3 (2020/21). The year 2019/20 was not taken into account because of the COVID situation that led to a modification of the teaching conditions. A total of 110 PSTs took part in the study (Cohort 1 included 17 participants, Cohort 2, 31 and Cohort 3, 62). Sample size was smaller in Cohorts 1 and 2 because only the PSTs that made all the activities about the DS were taken into account. It is to be noted that in the years corresponding to Cohorts 1 and 2 some of the PSTs made physical models representing the immune system, so they were not considered for this study.

The original sequence was structured in several stages as described by Jorba and Sanmartí (1996) (Figure 1). During the first stage, questions about DS allergies and intolerance were proposed in order to address participants' prior knowledge of the subject. As an example, participants were asked if they knew what happens in the body when you are milk intolerant and were requested to draw the necessary elements and processes on an image of a human body silhouette. To facilitate the graphic representation and avoid making very small diagrams or complicating the drawing of the silhouette, they were given a human silhouette of about 15 cm tall. PSTs then sought information to review and reconstruct their initial models in small groups (3-5 people), with the tutor´s help. After that, co-evaluation was made. Then, the groups reflected and wrote what happens, where it happens and how to represent it in a three-dimensional and dynamic physical model. After creating the physical models, these were presented to the rest of the groups and the authors evaluated them following the CMP framework (Hmelo-Silver et al. 2017) (Table 2), adapted to the task and the data iteratively.

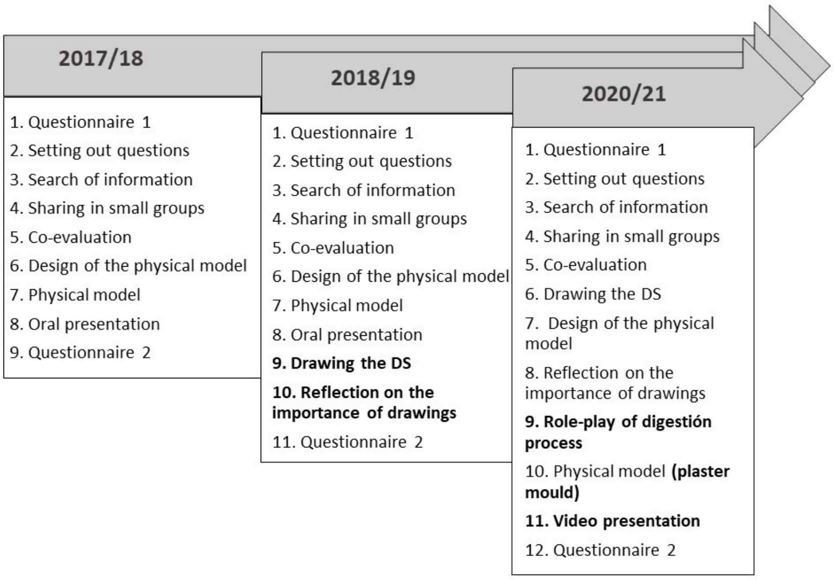

Figure 1. Teaching sequence implemented in 2017/18 and subsequent modifications 2018/19 and 2020/21 (modifications highlighted in bold)

In the case of Cohort 2 we added a modification: after making and presenting the physical models, the PSTs made a drawing of the DS and later reflected on the importance of the drawings for the representation of mental models, as well as the most common errors regarding the structure of the DS described in the bibliography. For Cohort 3, two new modifications were added: (1) Before making the physical model, a dramatic activity of digestion was performed in large groups (20-25 students). For this purpose, they drew the different organs and the route to be taken on the ground, and the PSTs represented the different macronutrients and enzymes involved and the processes they undergo throughout the DS. The dramatic activity was an experiential and scripted role-play with a structured frame, where participating roles and script were previously defined by the PSTs. As defined by Ødegaard (2003, p. 79), 'instead of merely transmitting knowledge of science from the science textbook or from the teacher, it has to be re-worked and re-constructed by the students'. The execution of the activity was guided by the teacher ensuring that the participants were able to participate in the activity and perform the role by themselves, but who was not actually involved in performing any of the roles. And (2) for the creation of the physical models, and in order to improve the three-dimensionality of the structural elements, each group was given a three-dimensional plaster mould of the back of the human torso, which was made by the authors. The groups had to put the organs they were building into this mould. Also, the presentation of the model consisted in the production of a video in which digestion was explained using the physical model. Finally, in order to know the PSTs' opinion about the teaching sequence, they were asked to grade from 0 to 5 the different didactic strategies used in the sequence and describe how each one contributed to their learning process. In addition, the PSTs indicated which strategy they would choose as future teachers. The description of the final teaching sequence (Cohort 3) is shown in Table 1.

Table 1. Final teaching sequence including: learning stage, chronology in weeks, objectives and tasks (OUT = out of class).

Learning stage	Week	Objectives	Tasks

Stage 1: Exploration	1	Express knowledge	1. Questionnaire 1
		Agree in small groups on the information needed to answer correctly	2. Setting out questions
Stage 2: Introduction of knowledge	OUT	Search for information about the questions	3. Search for information
	2	Share information in small groups	4. Sharing in small groups
		Co-evaluation. Revise ideas	5. Correction of each other's questionnaire
Stage 3: Structuring	2	Draw the DS in small groups	6. Drawing the DS
	2	Define what happens, where it happens and how they will represent it in the physical model and in the role-play	7. Design of the physical model and the role-play
	OUT	Reflection on the importance of drawings	8. Reading of 2 scientific articles on the subject
	3	Represent in a dramatized way the different macronutrients and enzymes involved and the processes they undergo throughout the DS	9. Role-play of digestion
	OUT	Represent their knowledge by a 3D and dynamic physical model	10. Physical model
		Represent their knowledge through an explanatory video of digestion using the physical model	11. Video Record
Stage 4: Application	4	Express knowledge	12. Questionnaire 2

Data Analysis

With regard to the first research question, at the beginning and at the end of the activity sequence, we analysed the drawings and answers written by the PSTs to the question *What happens in your body when you drink milk if you are intolerant?* (N=17 in Cohort 1, N= 31 in Cohort 2, and N= 62 in Cohort 3). Both written explanations and drawings were analysed according to the CMP framework adapted by Snapir et al. (2017) from Hmelo-Silver et al. (2017), which was adapted to the task and the data iteratively (Table 2). The components could be microscopic (C1) or macroscopic (C2). Given the context of the question, the microscopic agents were primarily the various enzymes that act throughout the digestive system (Snapir et al. 2017), and the macroscopic ones, the organs themselves. In the case of the macroscopic components, the drawings were analysed by adapting the approach of Reiss and Tunnicliffe (2001): several levels were established based on the number of organs drawn and whether the drawings represented the system. Like Reiss and Tunnicliffe (2001), the idea of system was considered to be present if there was an uninterrupted connection between the mouth and the anus, and if there were more than three organs represented.

For the Mechanisms, several levels were established according to the number of digestive processes (Snapir et al. 2017) in the context to which they referred (e.g. digestion of food, absorption of nutrients, fermentation in the large intestine). Phenomena are the outcome of the operating mechanisms (Snapir et al. 2017), i.e. the regulatory, plastic, energetic functions performed by the absorbed nutrients, as well as the symptoms in the case of intolerance.

Table 2. Established levels for CMP framework aspects (adapted by Snapir et al. (2017) from Hmelo-Silver et al. (2017)). In the case of the macroscopic components (C2), the levels were adapted from Reiss and Tunnicliffe (2001).

	C1: Microscopic components	C2: Macroscopic components	M: Mechanisms	P: Phenomena
Level 0	Lack of enzyme	No representation of internal structure	Lack of processes (digestion of food, absorption of nutrients, fermentation in the large intestine)	Lack of outcome of the operating mechanisms (functions of nutrients or symptoms in intolerance)
Level 1	Presence of enzyme	One or more internal organs not connected	Presence of one process	Presence of outcome of the operating mechanisms
Level 2		More than 3 internal organs with no relationships between them	Presence of two processes	
Level 3		Organ System	Presence of three processes	

The authors were trained in evaluating data from writings and drawings in a pilot project regarding the DS (previous years - data not shown); thus, data were, in this case, evaluated independently and, when necessary, doubts were discussed and consensus reached. An example of coding is shown in Figure 2.

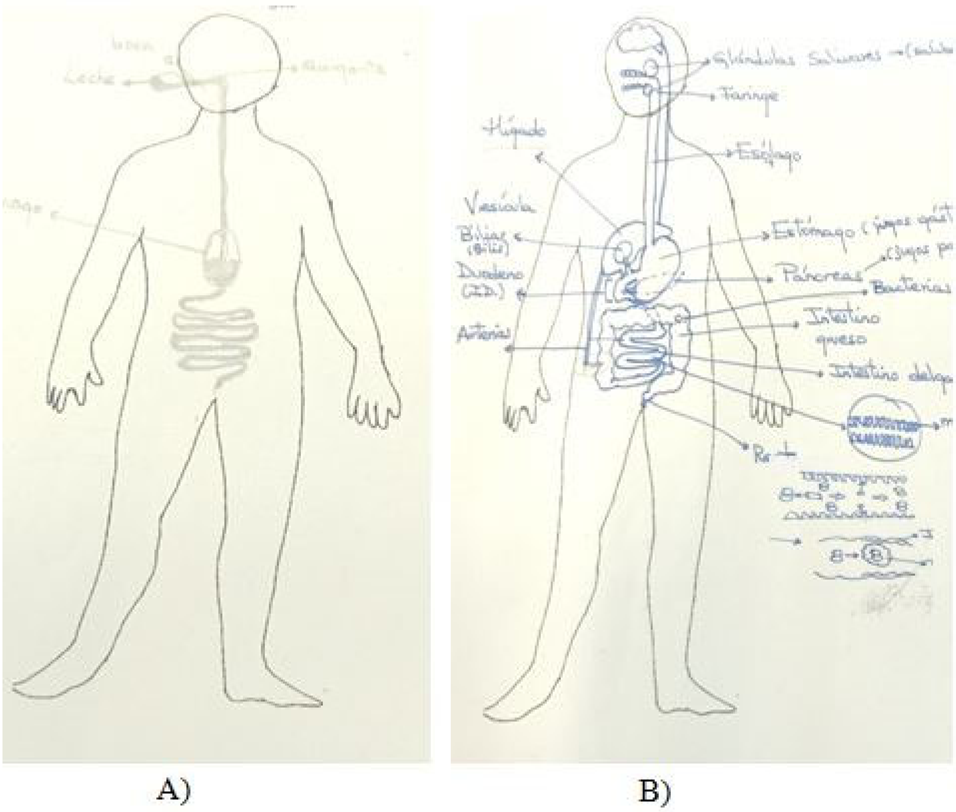

Figure 2. Pre- (A) and post- (B) drawings made by PST3.3.

The drawing in Figure 2A showed no enzymes, more than 3 organs, no system, no mechanisms and no phenomena, so it was coded as C1: 0, C2: 2, M: 0, P: 0. On the other hand, the drawing in Figure 2B did show an enzyme (the square), organs as a system, and various mechanisms (digestion shown as a division facilitated by the enzyme, fermentation shown as the molecule wrapped in a cloud, and explained in an annotation), but no phenomena, so it was coded as C1: 1, C2: 3, M: 2, P: 0.

Regarding the statistical analysis, the Wilcoxon test was used for comparing pre- and post-test scores within each cohort. The Kruskal-Wallis test was used for the measurement among cohorts (post-test in Cohort 1 versus post-test in Cohort 2; post-test in Cohort 2 versus post-test in Cohort 3; and post-test in Cohort 1 versus post-test in Cohort 3). The Bonferroni correction was used as a post hoc multiple comparison procedure to find non-parametric pairwise differences following a significant result from a Kruskal-Wallis analysis. The effect size was measured with Cohen's d values, which were calculated when pairwise comparisons were significant. For calculating the effect for pre-post comparisons in single groups (Cohort 1, Cohort 2 and Cohort 3), Cohen's d was calculated as the difference between the two group outcomes divided by the population standard deviation. For comparison of the post-tests between the cohorts, we adjusted the calculation of the pooled standard deviation with weights for the sample sizes. Before those test data were analysed, normality was checked by Q-Q plots (quantile-quantile plots) and by the Shapiro-Wilk test as supplementary to the graphical assessment. SPSS v26 was used for non parametric analyses and the Psychometrica calculator for the effect size (Lenhard and Lenhard 2016).

To address the second research question, we analysed the physical models constructed by the groups of PSTs and their oral presentations (5 in Cohort 1, 9 in Cohort 2, 18 in Cohort 3), the role-plays performed by the three groups in Cohort 3 and the individual opinions of Cohort 3 PSTs (N=62).

The role-plays were videotaped and transcribed. The videos, transcripts and models were analysed on the basis of the CMP framework jointly by the three researchers.

The opinions of the early childhood pre-service teachers were collected in the final questionnaire. They were asked to give a 0-5 score to five of the activities included in the sequence (search for information, drawing the DS, theoretical design of the model, role-play and physical model) based on their contribution to learning. They were also asked to explain the contribution and to describe what strategies they would use in early childhood to teach the human body topic.

Results

Development of Understanding about the Digestive System

For assessing the development of understanding about the digestive system, students' drawings and writings were evaluated in the beginning (pre-test) and at the end (post-test) of the process following the CMP framework (see methodology for further details). Results are given as relative frequencies (%) in Figures 3 (writings) and 4 (drawings).

In regard to the writings, we observe that students' understanding of the DS improved from the pre- to the post-test in all cohorts (Figure 3). Drawings improved following the same pattern (Figure 4). In both representation modes, students' understanding was more comprehensive in Components (C1 and C2), followed by Mechanisms (M). However, progress in Phenomena (P) was only observed in the writings. In fact, students always performed better in writings than in drawings.

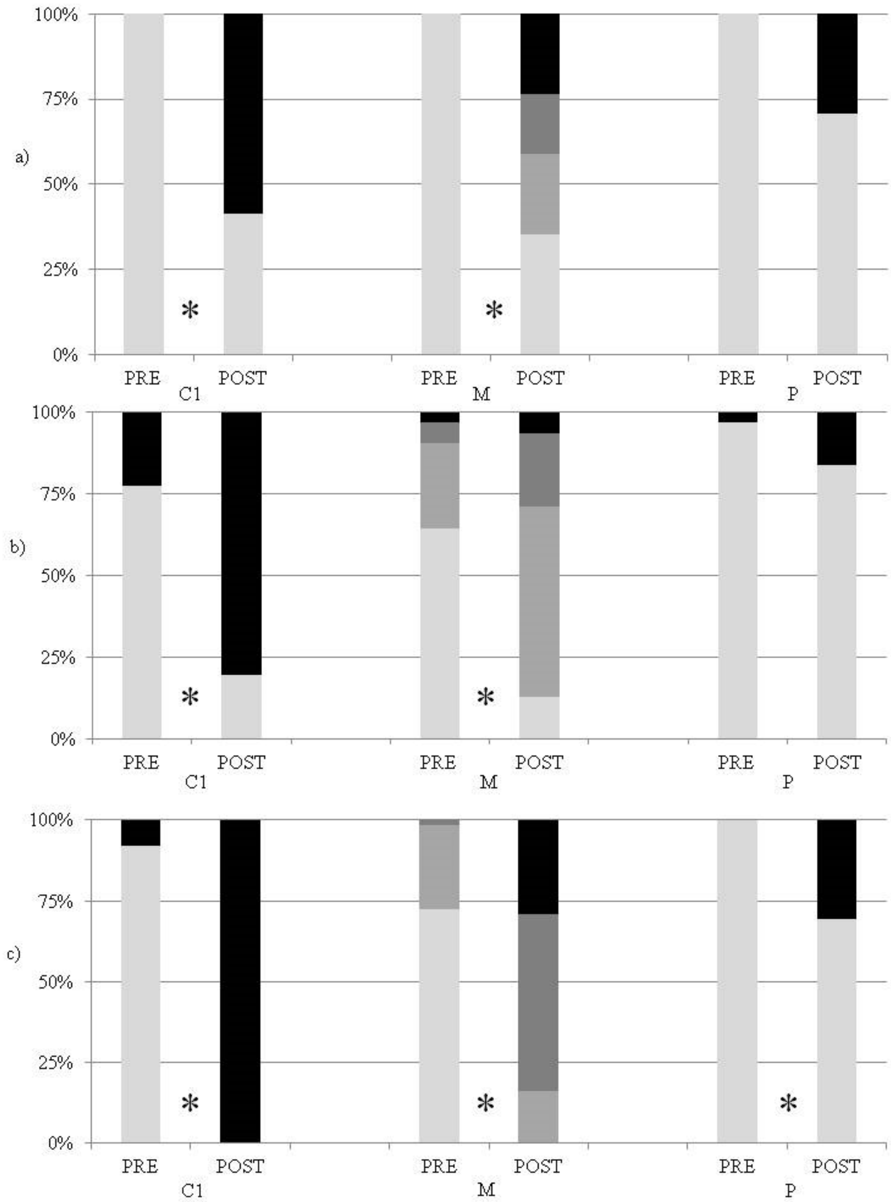

Figure 3. Relative frequencies of pre-and post-test scores for writings produced by three cohorts of third-year early childhood PSTs. C1 = microscopic components, M = mechanisms, P = phenomena. Levels are represented from lightest to darkest, so that black colour represents the highest level for each dimension (1 for C1, 3 for M, 1 for P). a) Cohort 1 (n=17); b) Cohort 2 (n=31); c) Cohort 3 (n=62). Stars between bars indicate a significant (p-value <0,01) difference between pre- and post- results.

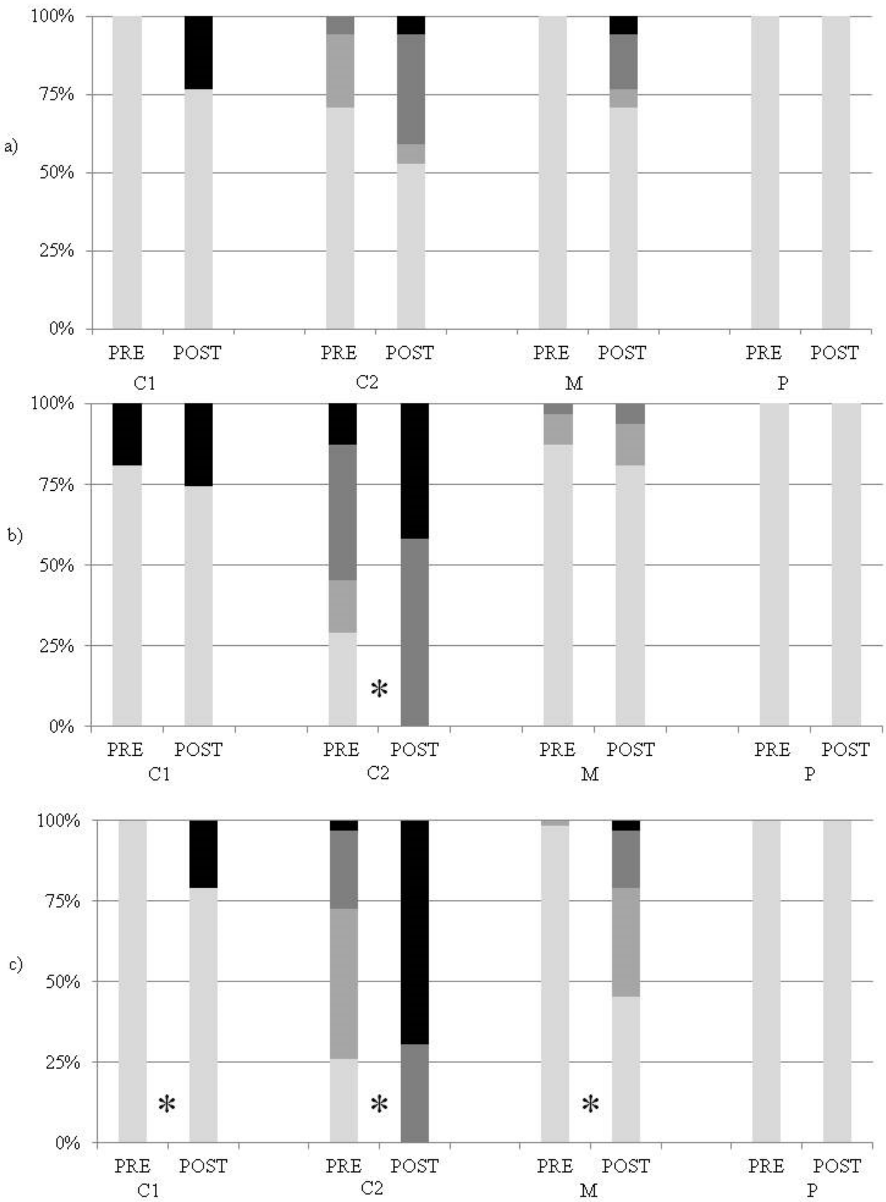

Figure 4. Relative frequencies of pre-and post-test scores for drawings produced by three cohorts of third-year early childhood PSTs. C1 = microscopic components, C2 = macroscopic components, M = mechanisms, P = phenomena. Levels are represented from lightest to darkest, so that black colour represents the highest level for each dimension (1 for C1, 3 for C2, 3 for M, 1 for P). a) Cohort 1 (n=17); b) Cohort 2 (n=31); c) Cohort 3 (n=62). Stars between bars indicate a significant (p-value <0,01) difference between pre- and post- results.

When comparing pre- and post-tests, improvements were observed in all three cohorts (Figures 2 and 3). However, the biggest improvement was achieved by Cohort 3, as confirmed by the statistical analysis (Table 3). As can be seen in Table 3, significant differences were found in writings with respect to components and mechanisms in all three cohorts, but only in Cohort 3 for phenomena. As for the drawings, the difference between Cohort 3 and the previous cohorts is even greater: in Cohort 3, the improvement was significant in both macroscopic and microscopic Components and in Mechanisms, whereas, in the previous cohorts, differences were observed only in macroscopic Components (Cohort 2). Cohen's d values were almost all above 0,8 which is usually considered a high effect, and all above 0,6, which corresponds to an excellent effect on students´ learning for innovative teaching proposals according to Hattie (2008). Note that the highest values were obtained in Cohort 3.

Table 3. Highly significant p-values (<0,01) as derived from Wilcoxon test results and Cohen's d values (effect size) in comparisons of pre- and post-test scores regarding microscopic components (C1), macroscopic components (C2), mechanisms (M) and phenomena (P) in writings and drawings within Cohort 1 (n=17), Cohort 2 (n=31) and Cohort 3 (n=62). Note that C2 was only evaluated in the drawings.

	Cohort 1		Cohort 2		Cohort 3	
	Writing	Drawing	Writing	Drawing	Writing	Drawing
C1	0,002 (d=1,64)	n.s.	0 (d=1,40)	n.s.	0 (d=4,74)	0 (d=0,723)
C2	-	n.s.	-	0 (d=1,25)	-	0 (d=2,52)
M	0,003 (d=1,51)	n.s.	0,002 (d=0,97)	n.s.	0 (d=3,14)	0 (d=1,27)
P	n.s.	n.s.	n.s.	n.s.	0 (d=0,93)	n.s.

Comparisons of post-tests across cohorts are shown in Table 4.

Table 4. Highly significant p-values (<0,01) as derived from Kruskal-Wallis test results and Cohen's d values in comparisons of post-test scores regarding microscopic components (C1), macroscopic components (C2), mechanisms (M) and phenomena (P) in writings and drawings between Cohort 1 (n=17) and Cohort 2 (n=31), Cohort 2 (n=31) and Cohort 3 (n=62) and Cohort 1 (n=17) and Cohort 3 (n=62). Note that C2 was only evaluated in the drawings.

	Cohort 1 vs 2		Cohort 2 vs 3		Cohort 1 vs 3	
	Writing	Drawing	Writing	Drawing	Writing	Drawing
C1	n.s.	n.s.	n.s.	n.s.	0 (d=1,181)	n.s.
C2	-	0 (d=1,948)	-	n.s.	-	0 (d=2,626)
M	n.s.	n.s.	0 (d=1,293)	0,005 (d=0,69)	0,006 (d=1,031)	n.s.
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

As data in Table 4 show, the biggest differences between the final results in the cohorts were found when the comparison was made with Cohort 3. When comparing final results of Cohorts 1 and 2, there was found a significant difference when drawing macroscopic components (C2). The comparison between Cohorts 2 and 3 indicates that the differences were centred on the mechanisms (in both representations, writings and drawings). Finally, the comparison between the cohort participating in the original activities (Cohort 1) and the cohort that carried the activities designed in the third iteration (Cohort 3) shows significant differences in all categories except Phenomena. Those results are reinforced by high Cohen's d values (> 0,6 according to Hattie 2008).

Learning Facilitation by the Construction of a Physical Model and Role-play

Physical Models

Concerning the physical models, improvements were also observed in the three aspects of CMP (Figure 5). In Cohort 1, the physical models included solid organs that did not allow food to pass through, or unconnected or unfinished systems (C2) (Figure 6A). In addition, the enzymes (C1), digestion processes (M) or the function of the nutrients once absorbed and the symptoms related to the processes (P) were absent in all the physical models.

In Cohort 2, an improvement was observed especially at the component level (Figure 5). Some students began to represent the whole DS as being connected (or at least consisting of more than 3 organs), although they still lacked 3-dimensionality, and sometimes, the enzymes were also represented (Figure 6B). Another aspect to consider was the presence of blood vessels, although this was usually just incidental because the students did not mention the nutrient absorption. In this sense, a slight improvement in the mechanisms was observed because some students used the physical model to explain the chemical digestion as a process. However, the PSTs still did not represent any phenomenon in their physical models. In Cohort 3, these improvements were maintained and even increased in some aspects (Figure 5), especially the macrostructural components (C2) - the DS was completely represented and organs were connected (Figure 6C) - and the mechanisms (M) -transformations undergone by the food were represented - (Figure 7) . It was also observed that the students made more use of the physical models in their explanations. However, phenomena still remain unrepresented in most cases.

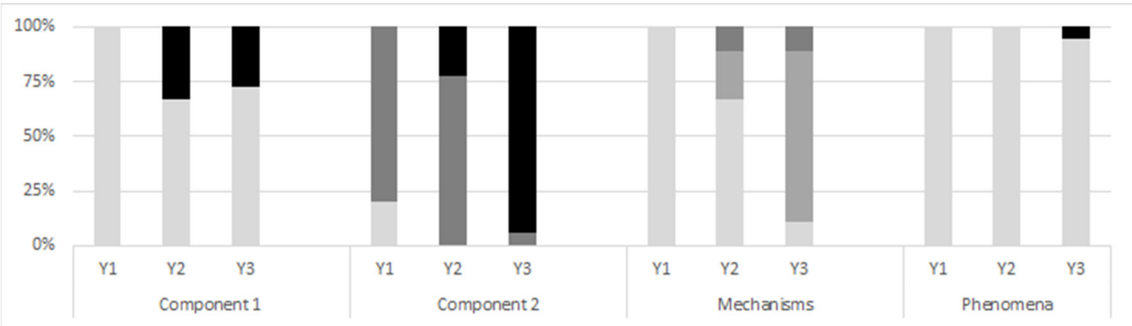

Figure 5. Relative frequencies of physical models produced by three cohorts of third-year early childhood PSTs. Component 1 = microscopic components, Component 2 = macroscopic components. Levels are represented from lightest to darkest, so that black colour represents the highest level for each dimension (1 for Component 1, 3 for Component 2, 3 for Mechanisms, 1 for Phenomena). Y1 = Cohort 1 (n=5), Y2 = Cohort 2 (n=9), Y3 = Cohort 3 (n=18).

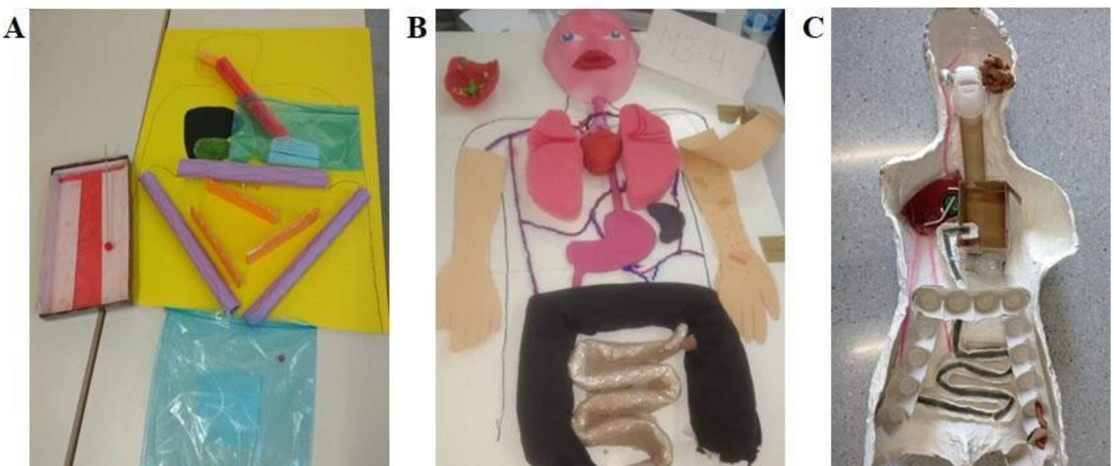

Figure 6. Examples of physical models made by third-year early childhood PSTs. A: unconnected organs and no presence of blood vessels. B: lack of 3-dimensionality and solid organs that do not allow food to pass through. C: connected organs that allow food

to pass through and view the transformation of the food through the DS, presence of blood vessels.

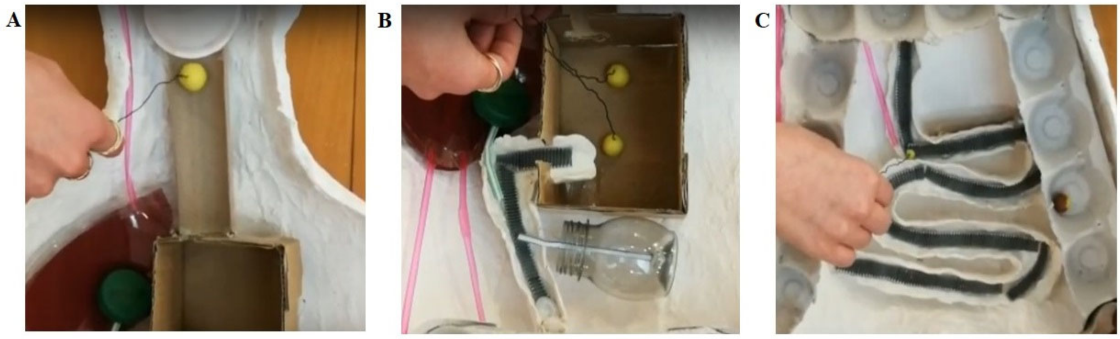

Figure 7. Examples of the transformations undergone by the food represented by third-year early childhood PSTs. A: food (represented with one ball of clay) passing through the oesophagus. B: first digestion of the food (represented with two balls of clay). C: nutrient (represented with a tiny ball of clay) ready to be absorbed to the blood vessels (represented with pink straws).

Role-play

The PSTs were actively involved in the design of the dramatic activity. Thus, different macronutrients were represented by groups of PSTs dressed in the same colour (e.g. blue for water, white for carbohydrates...) and holding hands. As they walked through the DS, they represented chemical transformations by separating hands. For example, Figure 8 shows large-chain proteins represented by several people holding hands and dressed in yellow. Enzymes (dressed in black) simulated breaking bonds between amino acids with their arms. Subsequently, these persons advanced separately and went through the intestinal wall pretending to be absorbed (Figure 8).

Figure 8. Screen capture of the videoed role-play played by third-year early childhood PSTs in Cohort 3 (n=62).

It is interesting to observe that, in all cases, participants mentioned food's pathway through the DS and specified details concerning each compartment's action. They specifically mentioned all the main associated organs and they represented the main processes that occur in the DS (digestion and absorption). The following examples illustrate C2, C1 and M categories respectively:

PST3.5: Well, we are the protein, we enter the mouth and mix with the saliva and go down the oesophagus until we reach the stomach…

PST3.15: I am the lactase enzyme that is responsible for digesting the lactose molecule because it is so large that otherwise it cannot be absorbed and passed into the blood [*simulates being a pair of scissors that separates two people*].

PST3.46: So now we are already smaller and we can go through here [*small intestine wall*], as we pass into the blood and we absorb ourselves.

PST3.32: Now we have a perfect size to be absorbed by the capillaries of the small intestine, reach the blood and pass through the liver, where the blood is cleansed and now distributed throughout the body.

However, once more, the PSTs did not go in depth into the phenomena.

Although they mentioned that nutrients are absorbed and distributed throughout the body or to a specific organ, they did not specify what we use the nutrients for*'once fully metabolized...since we are the nutrients our body needs, we will go from the blood vessels to the brain'*.

Opinions

When the PSTs were asked to rate each activity of the sequence, on a scale from 0 to 5, all the activities of the sequence were rated above 3 (search for information: 3.93±0.99, drawing the DS: 4.06±0.89, theoretical design of the model and the role-play: 3.67±1.16, physical model: 4.73±0.54, and role-play: 4.89±0.32). The most highly appreciated activities were the physical model and the role-play. They highlighted the fact that they were protagonists in the process:

PST3.10. [*role-play*] Being part of the process and planning how it will be recreated helps to internalise.

With regard to how the physical model had contributed to their learning process, 10% spontaneously mentioned that it had helped them to internalise the components:

PST3.27: [*physical model*] Thanks to this, we have seen something as realistic as possible in order to locate the elements and their connections.

Moreover, they reported that the physical model and the role-play had facilitated their understanding and internalisation of DS processes (29% and 43% of participants respectively).

PST3.17: [*role-play*] The most useful thing. The whole process and the sub-processes can be perfectly understood thanks to the fact that everything that happens is dramatized and physically seen.

Finally, 85% suggested the use of a physical model or a role-play to teach the topic of the human body in early childhood education. There were no differences in favour of one or the other, and 34% proposed using both.

Discussion

The results of the present study show that the PSTs developed an understanding of the DS that was reflected in all dimensions of systems thinking according to the CMP framework (Hmelo-Silver et al. 2017). The improvements observed in all three cohorts (n=17 in Cohort 1, n=31 in Cohort 2, n=62 in Cohort 3) were greater in Components than in Mechanisms or Phenomena. These dimensions improved especially in Cohort 3, i.e. in the third iterative cycle of changes over the sequence. This is consistent with Hmelo-Silver and Pfeffer's (2004) idea that thinking about Components, especially visible ones (C2 in this case), is what novices do primarily, i.e. it requires lower-level thinking.

Those improvements were reflected in both assessment tasks, the drawings and the writings. Note that the same pattern was observed, with the PSTs always being better at writing explanations than at drawing. Previous research pointed to similar differences between writings and drawings (Burgoa et al. 2017). Also, other authors such as Gómez (2008) found both differences in performance between modes of representation and specific difficulties in drawing. However, drawings have also shown potentiality in multilingual contexts as a universal language for facilitating young students to represent what they know, compared to written assessments (Dempster and Stears 2013).

In relation to the macroscopic Components of the DS in the drawings (C2), many of the misconceptions described in the literature and that were present in our PSTs´ pre-drawings were improved, such as not properly locating the digestive organs (Mohapatra and Roy 2018), or not understanding the DS as a tube where the food has to pass through and undergo digestive processes (Garcia-Barros et al. 2011; Talamoni et al. 2017; Banet 2008). Another improvement related to macroscopic components that was detected, especially in Cohort 3, was the presence of DS-associated organs (mainly liver and pancreas) - organs that do not perform any digestive or absorptive actions directly, but that constitute important structures associated with the DS (Hall 2016). Mattos Feijó et al. (2020) suggest that a greater understanding of the physiological aspects of DS-associated organs is important in overcoming the epistemological obstacles and alternative conceptions associated with the topic and may help to develop a global view of the human body as an integrated unit. Certainly, we detected that processes that occur in the DS such as chemical digestion, absorption or bacterial fermentation (Mechanisms) were gradually improved in the writings and even in the drawings in Cohort 3, although they still had deficiencies that may be explained by the fact that textbook sketches and drawings do not always treat this topic accurately (Carvalho and Alves 2004). The shortcomings found in Mechanisms and especially in Phenomena, even in Cohort 3, may also be due to their higher cognitive demand (Hmelo-Silver and Pfeffer's 2004). Regarding Phenomena, students eluded this in both physical models and drama, probably because the task did not force or encourage them sufficiently to incorporate Phenomena in those activities. For instance, in order to explain the obtention of energy in the cells from carbohydrates, students must add macro and micro Components first. We observed that many students added blood vessels and explained that macronutrients were transported via these; however, cells were absent, and, consequently, the related Phenomena too. With regard to reflecting how the digestive processes cause symptoms in the case of intolerance, although the context was made explicit in the questionnaire, this was not the case of the role-play or the physical models. In future interventions, the context for the physical models and the role-plays should address Phenomena in some way. Investigation should also be done on how that context facilitates the incorporation of the outcomes of the processes (i.e. the Phenomena dimension) into the activities throughout the sequence, as well as how this is transferred to the final writings and drawings.

In the case of research question 2, results from several data analysed show that both physical models and role-play were of key importance in Cohort 3; this may explain the greater improvements in this cohort than in the others. Thus, it was found that the physical models made by PSTs in Cohort 3 represented the macroscopic

Components of the system (C2) and the Mechanisms better than in previous years, even with the majority representing the idea of a system (Snapir et al. 2017). The reason may be the fact that all groups had to use a plaster mould given to them. This may have prevented the appearance of the pseudo-3D physical models made by PSTs in previous years, physical models with relief but which did not allow substances to pass through. In fact, none of the physical models in Cohort 3 (n=18) were of this type, whereas almost half were in Cohort 1 (n=5) and Cohort 2 (n=9). In that sense, we agree with Gómez (2008) and Ogan-Bekiroglu (2007) that students' representations of their ideas depend on the given representation type and format. Moreover, building 3D models facilitated visualization of the system itself, in contrast to 2D or pseudo-3D models (García and Mateos 2018), leading to a better understanding of Components and Mechanisms. In addition, building 3D models means creating 3D elements. For that purpose, the PSTs in Cohort 3 selected material that reflected other properties of the DS that had been ignored by PSTs previously (*e.g.* cardboard and/or playdough had been used in some groups as the sole material) and that were not needed in drawings and writings. Similar results were found by Gómez (2008) when building the human senses and nervous system model. Regarding communication, in order to express their mental models, all PST groups needed to make them dynamic; this may have helped with several common misconceptions listed above, especially with the one related to the continuity of the digestive tube. The PSTs' perception of the contribution of physical models to learning underlined those ideas, highlighting the potential of the physical model to represent Components and Mechanisms.

With regard to the role-play, results showed that all groups prepared scripts taking into account Components and Mechanisms. Also, this strategy helped the students to differentiate between the different types of macronutrients. In fact, a study conducted by Leite and Rotta (2016) found that high school students were not able to distinguish clearly between the concepts of food and nutrients. In our study, although it has not been analysed, we observed that in Cohort 3 PSTs mentioned the main classes of nutrients that the body needs and that different enzymes and organs are needed for their chemical digestion, after taking part into the role play.

PSTs valued very positively the contribution of the role-play for understanding Mechanisms. Previous studies have already shown the potential of dramatic activities, including role-play, as teaching/learning strategies for processes such as sound transmission (Braund and Ahmed 2019), heat transfer (Abed 2016), cellular processes (Walan 2020) or the numerous processes for which McSharry and Jones (2000) proposed the use of role-plays. Arguably, the physical movement involved in dramatising processes facilitates the internalisation of the inherently dynamic nature of these processes, which is not easily represented in other resources such as models. As indicated by McSharry and Jones (2000) and Braund and Ahmed (2019), role-plays are effective because the physical experience of representing abstract content facilitates assimilation. Another factor that makes dramatic activities effective is the students' sense of ownership of the task (McSharry and Jones 2000), which was reflected in the PSTs' opinions about role-play.

This is a case study, and, thus, generalisability of the outcomes would require more investigations on combining physical models and role-plays. Nevertheless, overall results point to the conclusion that introducing physical models and drama in the sequence brought a deeper and more accurate understanding of the DS. In Cohort 3, the PSTs were asked to build the DS model using both strategies and to describe and explain their understanding in a variety of forms (namely, writings, drawings, physical models and drama). One of the constraints to implementing innovations of this type is the amount of time dedicated (four weeks). Therefore, the question of how to optimize time to ensure that student learning is meaningful remains open. A case could be made for using role-play rather than building models. However, the results of this study suggest that it is the combination of these strategies that has a high potential to contribute to learning. The importance of using multiple representations and its implications for instruction are well known in the literature. In fact, this is exactly what scientists do: they use multiple representations and transform one mode into another equivalent one in order to find the answer to a question or solve a given problem (see Kozma et al. 1997 for an example with chemistry). As reviewed by Ainsworth (1999, 2006), multiple representations serve three main functions: to allow for complementary roles or information, to constrain interpretation, and to construct deeper understanding. Students inevitably had to address all three in order to answer the initial question *What happens to your body when you drink milk if you are lactose intolerant*?. As discussed above, the PSTs built their models with complementary information gained throughout the different tasks in order to deepen their understanding. Both physical models and drama required the new information to be used. For instance, the fact that the material in the physical model reflected properties of the organs (new information) together with the dynamism and their active participation in the role-play necessarily drove students to make the DS a continuous tube.

To sum up, it can be concluded that the construction of physical models and role-play are teaching strategies with high potential for the development of systemic thinking about the human body systems, for example the DS. This experience was developed with early childhood PSTs, who improved their knowledge and perceived the positive contribution of the teaching strategies to their learning process. It would be desirable for these results to be reflected in their future professional practice in early childhood education classrooms. To further study if the present findings would apply to children, our future research will focus on investigating how adolescents and younger children make use of the different teaching strategies and learn about the human body.

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