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Teaching digestive system: Spanish pre-service teacher's learning difficulties and alternative conceptions

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Abstract

The aim of the research was to analyze the learning difficulties and alternative conceptions that Spanish pre-service teachers have about digestive physiology and anatomy. The study was conducted on a primary education bachelor's degree biology course during the 2021/2022 academic year (n=91). The participants were asked to complete a conceptual test before (pre-test) and after the instruction (post-test). The results revealed that they had a limited knowledge of the digestive process before instruction (pre-test), especially those in the humanities baccalaureate group. Numerous alternative conceptions were identified, for example, that digestion ends in the stomach, mechanical digestion takes place only in the mouth, and nutrient absorption and transport into the bloodstream are not part of the digestive process. The results also indicated that levels of knowledge increased significantly after the course was completed (post-test); however, several features of the digestive process remained poorly understood, mainly because of the pre-service teachers' lack of understanding of the cellular or molecular aspects that govern this process and their inability to distinguish between macro and micro levels of digestion. It is therefore recommended that the pre-service teachers acquire a comprehensive knowledge of the digestive by studying other scientific disciplines (physics, chemistry, cell and molecular biology, and so on).

Keywords: alternative conceptions, digestive system, pre-service teachers, science education, learning difficulties

INTRODUCTION

In science teaching, it is particularly important to know the obstacles and difficulties that students have in identifying, differentiating, prioritizing, developing hypotheses, interpreting information, and planning strategies for solving problem situations (Campanario, 2000). This knowledge provides valuable information when designing and implementing teaching–learning strategies in the classroom, such as planning activities that students are able to carry out on their own and that, at the same time, allow them to progress adequately in their learning. This process, where the student must know, develop and use his or her own abilities in order to develop personal strategies that provide more effective learning, is known as self-regulation of learning (Castillo & Cabrerizo, 2003; Schraw et al., 2006).

Basically, the aim is that the student can build his or her own knowledge by overcoming obstacles and difficulties during the learning process (García-Carmona, 2011; Gómez & Sanmartí, 2002; Michael, 2007; Modell et al., 2004). To this end, it is essential to know the prior knowledge that the student has about a given content, in this case, of a scientific nature, and to determine whether this knowledge is in line with 'scientifically accepted ideas' or whether, on the contrary, it is rather an alternative conception or erroneous belief that the student must restructure and correct. One of the major problems facing science teaching is the existence of strongly rooted alternative

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Contribution to the literature

- The present study fills a gap in the literature regarding the main learning difficulties and alternative conceptions that pre-service teachers have concerning the digestive system.
- The results show that pre-service teachers, mainly those coming from the humanities baccalaureate, have a limited knowledge of the digestive system. In addition, they have many alternative conceptions, probably carried over from their previous educational stages, which prevent them from deepening and advancing in their knowledge of this subject.
- This is especially important because incorrect or inadequate teacher training in science, as a participant in the didactic transposition, could lead to a lack of understanding of science and learning errors by future pupils (primary school students), hindering proper scientific literacy. There is a need to improve the initial training of these future teachers and for this, it is essential to use active methodologies in which the student participates and applies scientific reasoning to achieve a much deeper understanding of the subject instead of the rote learning to which they are accustomed.

conceptions in the minds of students, which are very difficult to change and, in some cases, survive long years of schooling. These preconceptions are mental constructs that students develop in response to their need to interpret natural phenomena or scientific concepts, and to provide explanations, descriptions or predictions but which, in many cases, if not properly guided, can contribute to reinforcing students' difficulties in learning science (Belachew, 2020; Chi, 2005; Chi & Roscoe, 2002; Chin & Pierce, 2019; Treagust & Duit, 2008; Vosniadou, 2007). It is therefore essential for teachers to be aware of the main preconceptions that their students may have, those that they themselves may have, those found in teaching materials and textbooks, and based on this, to constantly seek teaching strategies that promote conceptual change among their students (Anggoro et al., 2019; Bahar, 2003; Cakir, 2008; Duit & Treagust, 2003; Sinatra & Mason, 2008).

The existence of alternative conceptions about digestion and the digestive system among students at different educational levels has already been highlighted by numerous authors (Ahi, 2017; Allen et al., 2019; Aydin & Ural, 2018; García-Barros et al., 2011). A review of the literature indicates that, at the most basic levels of education, there is a general tendency to consider digestion as an exclusively physical process in which food is broken down to separate good substances from bad; that it is also chemically modified and reduced to components that can be absorbed by the body is not considered (Cakici, 2005; Carvalho et al., 2004; Rowlands, 2004; Teixeira, 2000). Logically, these explanations are more precise at higher educational levels, referring to the decomposition of food by physical and chemical actions into substances that can be assimilated by the organism; however, many of these definitions still contain or hide inaccuracies of greater or lesser scope, such as the omission of the stage of absorption and transport of nutrients into the bloodstream and tissues (Cucin et al., 2020; Ozsevgec et al., 2012). Another widespread idea is to consider the stomach as the central organ of the digestive process, where all the digestion of ingested food and the absorption of nutrients would take place, assuming that digestion begins in the mouth and ends in the stomach, and consequently relegating the role of the intestines to mere reservoirs where waste substances would be stored, but in no case with digestive activity (Gungor & Ozgur, 2009; Ozgur & Pelitoglu, 2008). It is also necessary to point out that the importance attributed to the mouth is fundamentally related to actions of a mechanical nature, since in most cases saliva is not considered as a fluid with digestive actions, but simply serves to moisten the food and facilitate the movement of the food bolus. Something similar would happen with digestive juices to which these same two functions are attributed, but without considering their participation in the chemical decomposition of the food (Cakici, 2005; Teixeira, 2000).

The above-mentioned studies have significantly increased the knowledge of alternative conceptions about digestive physiology. However, it should be noted that most of these studies have been carried out in the early stages of education (early childhood and primary education). This is one of the main reasons that motivated us to propose the present research since studies about pre-service teachers' alternative conceptions about the digestive system are scarce. This is especially important because incorrect or inadequate teacher training in science, as a participant in the didactic transposition, could lead to a lack of understanding of science and learning errors by future pupils, hindering proper scientific literacy. Another reason that has led us to carry out the present study is the strong presence of content related to human anatomy and physiology in basic education. In the Spanish primary school curriculum, intended for children aged six to 12, this content is located within the 'nature sciences' area, and more specifically within block 2 ('the human being and health'), including aspects such as the vital functions of the human being, the systems and/or apparatus involved in nutrition and their interrelation, the organs, which permit such functions to be performed, healthy eating and a balanced diet, healthy lifestyle habits, etc. It is therefore logical to think that if these contents are so important as to be taught throughout a whole educational stage, such as primary education, it is not surprising that teachers need to be adequately trained to teach them correctly in the classroom.

Research Problem and Purpose of the Study

One of the main factors influencing the learning process, apart from those directly related to the student, is the quality of the teaching received, and more specifically, the teacher's knowledge of the subject. Numerous studies have shown that poor subject knowledge leads to greater reliance on the textbook, a greater number of less cognitively demanding activities, more difficulty in setting learning goals and teaching strategies, and a higher incidence of alternative conceptions amongst students (Ball et al., 2008; Kaya, 2009; Valanides, 2000). This problem is particularly acute in social science degrees that include a scientific component (e.g., the BEd degree in primary education) with which students are often not familiar. For this reason, and taking the present context into account, we carried out an exploratory study on the learning difficulties regarding basic concepts relating to digestive anatomy and physiology amongst a group of pre-service teachers, analyzing their possible alternative conceptions and the persistence thereof after instruction.

Therefore, the aim of the present study was to analyze the pre-service teachers' learning difficulties and alternative conceptions about the digestive system and to assess whether these ideas persist after science instruction at the university. To accomplish this aim, the following research questions were posed:

1. What are pre-service teachers' alternative conceptions of the digestive system?
2. What is the effect of instruction on reducing the incidence of these alternative conceptions?
3. Does pre-service teachers' pre-university training influence the frequency of these alternative conceptions?
4. What are pre-service teachers' learning difficulties regarding the digestive system?

MATERIALS AND METHODS

Participants and Study Design

The participants were recruited during the academic year 2021/2022 using non-probability convenience sampling and consisted of 91 second-year pre-service teachers on the BEd degree in primary education at the University of Valladolid (Spain) who were studying subject curriculum development in the experimental sciences. All pre-service teachers voluntarily agreed to participate in the study by signing the informed consent form, and no personal data were collected at any time to ensure anonymity.

A single group pre-/post-test study was carried out to evaluate the alternative conceptions that the pre-service teachers had concerning the digestive system and the digestive process. The research design followed a mixed-method approach in which qualitative and quantitative data were collected. The latter included information about statistical comparison of test scores and demographics, for example, age, sex, and pre-university study. Qualitative data were used to analyze the test scores and provide more details about the patterns of the pre-service teachers' alternative conceptions. Before instruction, a conceptual test was given to the pre-service teachers (pre-test, n=91). Subsequently, theoretical and practical classes were given by the teachers responsible for the subject (**Appendix A**). The same test was then retaken (post-test, n=86).

Research Instrument

The research instrument used to assess the level of knowledge of the pre-service teachers and to detect possible alternative conceptions is presented in Appendix B. It was validated by three professors (with more than 10 years of experience) from the Department of Didactics of Experimental Sciences at the University of Valladolid, who assessed the items with respect to the construct, content and suitability, establishing the appropriate considerations/recommendations for improvement. Subsequently, and based on this first review, a second version was drawn up, which was subjected to a second validation process (pilot test with 10 pre-service teachers on the primary education degree course), establishing the final version of the instrument provided to our study population. The test included 10 questions relating to the conceptual and procedural aspects of the digestive process of which nine were open-ended and one was multiple-choice (**Appendix B**). We included a section in the test dedicated to socio-demographic data, for example, age, sex, and pre-university study.

The answers were evaluated independently by two education department professors, who designed a system for coding and categorizing the answers for each of the questions. The coding agreement rate was >90%, and where discrepancies arose, a third department teacher acted as arbiter. Tasks with no or illegible answers were excluded from the analysis. The answers were coded 'C' for correct and 'I' for incorrect. The correct answers that fulfilled the criteria of quantity, type, or diversity of terms used were categorized as excellent ('E'), reflecting a greater mastery of the subject.

Statistical analysis was performed using R version 3.5.3 (R Core Team, 2019). For each item, a descriptive analysis was applied at each stage, using as descriptive

Table 1. Percentage of pre-service teachers' correct answers before (i.e., pre-test) & after (i.e., post-test) the experimental sciences course

No	Task description	Pre-test (%)	Post-test (%)	p-value	Significance
1	General process of food digestion	64.5	83.3	<0.0100	Significant
2	Digestive system anatomy	43.0	64.3	<0.0100	Significant
3	Difference between mechanical & chemical digestion	55.9	75.0	<0.0500	Significant
4	Mechanical digestion processes	62.4	92.8	<0.0001	Significant
5	Anatomical distribution of the digestive processes	8.6	47.6	<0.0001	Significant
6	Digestive functions of saliva	73.2	90.5	<0.0100	Significant
7	Differences between food bolus, chyme and chyle	41.9	78.6	<0.0001	Significant
8	Nutrient absorption	60.2	80.9	<0.0100	Significant
9	Lactose intolerance	18.3	56.0	<0.0001	Significant
10	Importance of a diet rich in fiber	12.9	51.2	<0.0001	Significant

Note. No: task number & Tasks with illegible answers were excluded from the analysis

statistics the percentages of each category together with a confidence interval of 95%. To evaluate the relationship with the demographic variables (age, sex, and pre-university itinerary), contingency tables and chi-square contrast were used to evaluate the independence hypothesis. In tables with small, expected values, Fisher's exact test was used. To evaluate whether the answers were significantly different across the two time points, the symmetry hypothesis was contrasted (i.e., to see whether the category changes of the variables occurred in both directions with equal probability). The McNemar contrast was used from the contingency table that crossed the two stages. Except for the items of multiple answers, the percentages of improvement, deterioration, or no change were also calculated, along with their confidence intervals.

RESULTS

The analysis of the post-test results revealed a significant improvement, both in conceptual and procedural aspects, over those of the pre-test; the average percentage of correct answers rose from 44% to 72% (**Table 1**). However, despite the explanations given during the classes and practical activities, there were certain aspects of the digestive process that remained misunderstood by a large part of the pre-service teachers, demonstrating the difficulties that these pre-service teachers present when assimilating certain biological processes.

Almost two-thirds of the pre-service teachers surveyed before the experimental sciences course correctly defined the digestive process that takes place in humans (task 1; **Table 1**). However, a high percentage of pre-service teachers (35.5%), mainly from the humanities baccalaureate group were not able to define it correctly (**Appendix C**). After instruction, most of the pre-service teachers surveyed correctly defined the human digestive process (task 1; **Table 1**). In addition, it is necessary to highlight that in the post-test not only did the number of correct answers increase significantly (83.3% vs. 64.5%) but so too did the cognitive level of these responses, categorized as 'E', mainly those in the science baccalaureate group ($p<0.001$), as more than 33% of the pre-service teachers surveyed cited terms such as ingestion, mechanical and chemical digestion, enzyme, peristalsis, segmentation, digestive juices, absorption, nutrients, bloodstream, defecation, etc. (task 1; **Figure 1**). Even so, more than 15% of the pre-service teachers surveyed were still not able to explain the digestive process correctly, repeating practically the same errors as in pre-test.

Slightly poorer results were observed in the pre-test when participants were asked to identify the structures or organs that are part of the digestive system (task 2; **Table 1**), more than half responded incorrectly (with less than 75% of the organs identified). The figure reached more than 70% in the humanities baccalaureate group ($p<0.01$). The pancreas, gallbladder and the salivary glands were the organs least recognized by pre-service teachers. After instruction, a significant increase was observed in the percentage of correct answers (from 43.0% in the pre-test to 64.3% in the post-test, task 2; **Table 1**). However, approximately one-third of the participants surveyed, mainly those in the humanities baccalaureate group ($p<0.01$), were still not able to identify most of the organs shown in the drawing.

The test results also revealed that only 55.9% and 62.4% of the pre-service teachers surveyed in the pre-test, mainly from the science baccalaureate group, correctly explained the differences between the mechanical and chemical digestion and the different mechanical processes that allow food to pass through the digestive tract, respectively (task 3 and task 4; **Table 1**). This result was even much worse (<10%) when pre-service teachers were asked about the anatomical distribution of these processes (task 5; **Table 1**). As was expected, the percentage of correct answers for the three tasks increased significantly in the post-test, especially the one relating to the mechanical digestion processes (task 4; **Table 1**), not only in terms of the number of correct answers but also the number of participants, mainly from the science baccalaureate group ($p<0.05$), who gave an 'E' answer (task 4, **Figure 1**), having specified nearly every mechanical digestive process

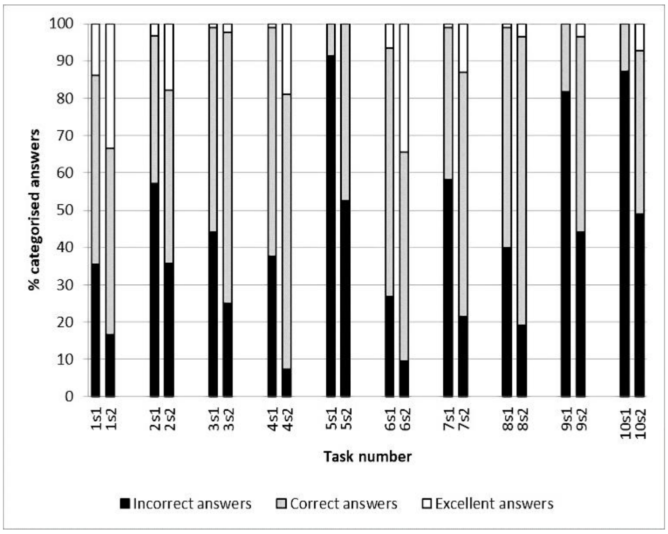

Figure 1. Percentage of pre-service teachers' categorized answers before (pre-test; s1) & after (post-test; s2) the experimental sciences course (tasks with illegible answers were excluded from the analysis) (Source: Authors' own elaboration)

(chewing, tongue movements, swallowing, peristalsis, churning, segmentation, and so on). When asked about the anatomical distribution of these processes (task 5, **Table 1**), more than half of the pre-service teachers surveyed answered incorrectly, repeating the same errors as in the pre-test.

The best outcome in the pre-test (>70%) was observed when pre-service teachers were asked to explain the importance of saliva in the digestive process (task 6; **Table 1**). As in previous tasks, this percentage was significantly higher ($p<0.05$) in the science baccalaureate group than in the other group. Another surprising result was when pre-service teachers were asked to color the food bolus, chyme, and chyle path (task 7; **Table 1**), since only 41.9% of the pre-service teachers surveyed, mainly from the science baccalaureate group ($p<0.05$), correctly answered this question. Slightly better results (>60%) were obtained when pre-service teachers were asked about the process of nutrient absorption (location and explanation) (task 8; **Table 1**). As was also expected, the percentage of correct answers for task 6, task 7, and task 8 increased significantly in the post-test (**Table 1**). In the post-test, not only did the number of correct answers increase significantly but also the number of 'E' answers (**Figure 1**), mainly regarding the digestive functions of saliva (from 6.5% in the pre-test to 34.5% in the post-test).

Finally, it is worth noting the poor results obtained in task 9 and task 10 in the pre-test (**Table 1**): more than 80% of the pre-service teachers, mainly from the humanities baccalaureate group ($p<0.05$), answered incorrectly. Although the percentage of correct answers increased significantly after the instruction, almost half of the pre-service teachers surveyed, again mainly from the humanities baccalaureate group ($p<0.05$), were unable to give a more or less reasonable explanations for task 9 and task 10 (**Table 1**), repeating the same errors as in the pre-test.

As **Table 2** shows, several alternative conceptions were identified concerning digestive physiology and anatomy.

For task 1, pre-service teachers were asked to explain the general process of food digestion. The most frequent alternative conception was that it is completed in the stomach, thus omitting the absorption and transport of nutrients into the bloodstream. After instruction, 15.1% of the pre-service teachers still failed to understand that the nutrients found in food pass into the bloodstream and thence into different organs of the body where they are used for metabolic purposes or building complex substances required by the body. For task 2, pre-service teachers were asked to identify in a figure the structures or organs that are part of the digestive system. Surprisingly, even after the instruction (34.9%), pre-service teachers had a limited knowledge of the anatomy of the digestive system, confusing organs or incorrectly locating them.

Task 3, task 4, and task 5 examined the pre-service teachers' knowledge of the concepts of mechanical and chemical digestion. The most common alternative conceptions related to the anatomical distribution (task 5; **Table 2**). The pre-service teachers firmly believed that mechanical digestion is limited to only the first steps of the digestive process (mastication or chewing) and that chemical digestion takes place in the stomach only. After instruction, 44.2% of the pre-service teachers still struggle with the idea that mechanical digestion takes place in the mouth only. Another widely held alternative conception was that the terms mechanical and chemical were interchangeable, and that food is only physically broken down (task 3 and task 4, **Table 2**).

Task 6 aimed to determine the pre-service teachers' knowledge of the digestive functions of saliva. The principal alternative conception was the result of a lack of knowledge of the presence of the enzymes in saliva (α-amylase, lingual lipase, and so on) that are responsible for chemical digestion in the mouth. For task 7, pre-service teachers were asked to color the food bolus, chyme, and chyle path. Most colored the food bolus in the mouth only, believing that chyme and chyle are formed in the stomach. After instruction, 18.6% of the pre-service teachers continued to confuse the pathway and/or place of formation of these substances.

For task 8, pre-service teachers were asked to explain the nutrient absorption process. Most were unable to indicate the final destination of the absorbed nutrients. After instruction, 12.8% of the pre-service teachers still omitted to mention that absorbed nutrients pass into the bloodstream and the lymphatic system. For task 9, pre-service teachers were asked to describe the pathophysiology of lactose intolerance.

Table 2. Percentage of pre-service teachers having alternative conceptions as determined by conceptual test before (pre-test) & after (post-test) the experimental sciences course

No	Alternative conceptions	Pre-test (%)	Post-test (%)	p-value	Significance
1	Not indicating complete process	25.3	15.1	<0.05	Significant
	Not mentioning digestive system or any organ.	3.3	0	>0.05	NS
	Not indicating food transformation process	2.2	1.2	>0.05	NS
2	Improper identification of structures and/or organs	57.1	34.9	<0.05	Significant
3	Improper definition of mechanical & chemical digestion processes	27.5	18.6	<0.05	Significant
	Confusion between mechanical & chemical digestion	2.2	2.3	>0.05	NS
4	A belief that chewing is the only mechanical digestion process	26.4	4.7	<0.01	Significant
5	A belief that mechanical digestion is limited only to the first steps of the digestive process that take place in the oral cavity	74.7	44.2	<0.05	Significant
	A belief that chemical digestion only takes place in the stomach	17.6	6.9	<0.05	Significant
6	Not mentioning the enzymes in saliva (chemical digestion)	20.9	5.8	<0.05	Significant
	Saliva only wets food to make it easier to swallow	4.4	3.5	>0.05	NS
7	Confusing the pathway and/or place of formation of these substances	36.3	18.6	<0.05	Significant
8	Not mentioning that the absorbed nutrients pass into capillaries (circulatory system) & lacteals (lymphatic system)	26.4	12.8	<0.05	Significant
	A belief that absorption of nutrients occurs in the stomach	12.1	2.3	<0.05	Significant
9	Indicate only symptoms of this intolerance without mentioning that lactose intolerance is caused by lactose malabsorption produced by reduced production of lactase	60.4	33.7	<0.05	Significant
10	A belief that fiber only prevents or relieves constipation	51.7	34.9	<0.05	Significant

Note. No: Task number; NS: Not significant; & Tasks with illegible answers were excluded from the analysis

After instruction, 33.7% were still unable to explain why lactose-intolerant people cannot eat foods that contain this sugar (i.e., lactose malabsorption caused by reduced production of lactase), indicating only some symptoms of this intolerance. Finally, task 10 aimed to determine the pre-service teachers' knowledge of the benefits of a fiber-rich diet. The main alternative conception, both before and after instruction, was to believe that the only benefit of dietary fiber was to prevent constipation.

Additional examples of answers mentioned by pre-service teachers within each category are presented in **Appendix C**.

DISCUSSION

The results obtained in this study show that our pre-service teachers have a moderate knowledge of the digestive process when they reach the university stage. Even though many of them know and understand the general functioning of this system and are even capable of giving scientific explanations of the different stages that make it up, numerous alternative conceptions have been identified among our pre-service teachers that prevent them from progressing in their learning. These results are consistent with those shown in previous studies with similar characteristics. For example, Andariana et al. (2020), in a study concerning biology education students' misconceptions about human anatomy and physiology, revealed that more than 70% of the participating pre-service teachers developed misconceptions about the digestive system, this being one of the most poorly understood systems of the human body. This problem is even more worrying in pre-service teachers coming from the humanities baccalaureate, where the results are notably worse, which is logical if we consider the scientific disconnection they have suffered before their arrival at university.

An overall analysis of the conceptual test completed by the pre-service teachers before the experimental sciences course shows, as mentioned above, that not all stages of the digestive process are perfectly internalized and that there are many alternative conceptions that need to be reorganized and restructured. An example might be the preconceptions that many of these pre-service teachers had about the general process of digestion, understanding it basically as a process of transforming food into much smaller molecules, but not appreciating that these nutrients must then be broken down into small enough parts for the body to absorb them and use them for energy, cell growth and repair. Another very recurrent example among our pre-service teachers was the erroneous belief that mechanical digestion of food only takes place in the mouth through chewing or that chemical digestion only takes place in the stomach, which is considered by many pre-service teachers as the central organ of digestion. As in previous studies (Cardak, 2015; Sasmaz & Ormanci, 2014), it is also necessary to highlight the poor anatomical knowledge that our pre-service teachers have on their arrival at university, not being able to identify and connect the main structures or organs that form part of this system, and even stating that digestion begins in the mouth and ends in the stomach, completely forgetting the rest of the structures or organs involved in this process. But what is really surprising and worrying is that all these alternative conceptions that we have been able to identify among our pre-service teachers have already been described in previous studies carried out with primary and secondary education students (Ahi, 2017; Allen et al., 2019; Aydin & Ural, 2018; Carvalho et al., 2004; Cucin et al., 2020; Teixeira, 2000), which indicates that these ideas have become so deeply rooted in students' minds that, despite years of schooling, they persist over time and are resistant to change, becoming misconceptions and contributing to the strengthening of the difficulties that students present when learning science (Halim et al., 2018; Lazarowitz & Lieb, 2006; Mintzes et al., 2005).

Human physiology is a difficult discipline to teach and learn as it contains many complex and abstract concepts (Brown et al., 2016; Johnston et al., 2015). In addition, it has many characteristics that favor the emergence and persistence of alternative ideas on the part of pre-service teachers (Andariana et al., 2020; Bordes et al., 2021; Reinoso et al., 2019; Versteeg et al., 2020). One of them is that it requires a comprehensive understanding of other related areas with a lot of practical content, such as molecular biology, histology, biochemistry, etc., disciplines far removed from the educational scope of our pre-service teachers and from the pre-university education received by most of them, thus becoming one of the main handicaps faced by our pre-service teachers. Traditional teaching and learning methods, where a generally descriptive and theoretical approach to the contents to be covered is promoted, are not usually the best allies to overcome these difficulties, making it necessary to change the methodological approach that involves some kind of cognitive conflict among students (Andrews et al., 2011; Badenhorst et al., 2016; Bahar, 2003; Sadler et al., 2013). As these authors point out, if these contents are only worked on memoristically, they tend to be quickly forgotten and students return to their previous idea, weakening the students' analytical ability and making it impossible for them to progress in their learning. This is probably what has happened with our pre-service teachers throughout their education and what has given rise to the existence of the aforementioned alternative conceptions, which demonstrates the need to use active methodologies in which the student participates and applies scientific reasoning to achieve a much deeper understanding of the subject instead of the rote learning to which they are accustomed.

As expected, pre-service teachers' knowledge of the subject improved significantly after taking the course, increasing not only the percentage of correct answers but also the quality of the answers (excellent answers). It is obvious that theoretical and practical sessions given by the teachers improved the pre-service teachers' understanding and helped many of them to reconsider their previous ideas about the digestive process. As mentioned above, rote learning is one of the main obstacles our pre-service teachers face, and so in this subject we have tried to avoid this model by implementing in the classroom active methodologies and a whole series of activities that involve pre-service teachers in their own learning process, such as practical cases, problem-solving, laboratory experiments, discussion activities or collaborative projects. Even so, there was a small percentage of pre-service teachers, mainly from the humanities baccalaureate group, who continued to make the same mistakes and maintain the same alternative conceptions as at the beginning of the course, either because of a lack of scientific background or because of a low level of interest in this type of content. This fact clearly shows the need to introduce changes in the teaching–learning methodologies of these subjects, especially in the early stages of education, if we do not want these students to arrive at the university stage as scientifically weighted down as they are at present, especially bearing in mind that, in our case, these are teachers in training who in the future will transfer all their knowledge and motivations to the children, which could lead to a misunderstanding of science by school students.

CONCLUSIONS AND IMPLICATIONS

The results show that the pre-service teachers had a limited knowledge of the digestive system and the digestive process. In addition, they have many alternative conceptions, probably carried over from their previous educational stages, which prevent them from deepening and advancing in their knowledge of this subject. As all the studies point out, one of the major problems facing science teaching is the existence in students of deeply rooted alternative conceptions, which are very difficult to change and, in some cases, survive long years of science instruction. The present study is a clear example of this, as we have been able to identify in a group of pre-service teachers practically the same alternative conceptions as those found in primary- and secondary-school students. In this sense, it is also necessary to qualify the differences found in terms of pre-service teachers' pre-university training, with the shortcomings identified in the humanities baccalaureate group being very notable. These learning difficulties are probably due to a lack of scientific background, low motivation towards this type of content and traditional teaching strategies based on excessive memorization.

The main implication of this work is the need to improve the initial training of these future teachers and for this, it is important that, in the first place, they acquire a good conceptual and epistemological knowledge of the scientific content they have to teach. Otherwise, they may incur certain inaccuracies or conceptual errors, which when transferred to their future students, would hinder the correct learning of schoolchildren. In this initial training, it will also be important to involve future teachers not only in the knowledge of the discipline, but also in how to teach it. They should become familiar with research on how to select and organize this content at a given educational level, what learning difficulties may arise, what teaching strategies to use, how to implement them in the classroom and how to evaluate whether the objectives are achieved. But before reaching this stage, it is first necessary to know the scientific knowledge that trainee teachers possess on their arrival at university, and not only that, but also the alternative conceptions associated with these contents and their possible origin, as this will allow us to adapt the teaching–learning strategies to the difficulties, needs and real knowledge of the pre-service teachers.

In view of the results obtained in this work, and more specifically, after having verified that the alternative conceptions identified among our pre-service teachers about the digestive system are practically the same as those observed at previous educational levels, it seems more than evident that there is a need to reflect on the methodologies habitually used to teach this type of content. It is obvious that traditional teaching methods based on the transmission–reception of information and on predominantly conceptual and rote learning are not the best option to ensure that pre-service teachers learn science effectively. We must therefore consider a methodological change that promotes meaningful learning of science content and that allows us to eliminate these alternative conceptions. This new educational environment must also be able to increase pre-service teachers' motivation to study and foster positive emotions and attitudes towards learning. One possible proposal could be the implementation, at all educational levels, of active methodologies (project-based learning, flipped classroom, gamification, problem-based learning, enquiry, service learning, cooperative work, etc.), where students are the true protagonists and responsible for their own learning, promoting critical thinking and student participation. In this regard, a future perspective of this work will be for trainee teachers to design socio-constructivist-oriented teaching sequences on biology-related topics, such as human physiology, which they can then implement with their future students to improve their conceptual and procedural knowledge.

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Ethical statement: Authors stated that the study did not require formal ethics approval. The data was completely anonymous with no personal information being collected (apart from age, sex, pre-university itinerary, and a record of informed consent). The data was not considered to be sensitive or confidential in nature. The data was used for a purpose, which falls within the remit of the original consent provided by subjects. The issues being researched were not likely to upset or disturb participants. The subject matter is limited to topics that are strictly within the professional competence of the participants. Vulnerable or dependent groups were not included. There was no risk of possible disclosures or reporting obligations.

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Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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APPENDIX A

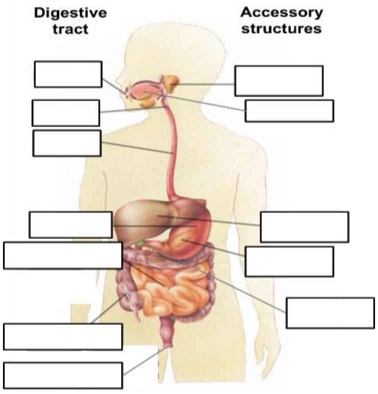
Table A1. Subject structure

Type of classes	Activity descriptions
Lectures (10 sessions) (90 min/session)	Theoretical presentation of content: The teacher explains the topic in class with the support of a multimedia presentation. Major concepts: - Digestive system anatomy (three sessions) - Ingestion and swallowing - Mechanical digestion - Chemical digestion (two sessions) - Absorption - Metabolism - Digestive system pathologies
Seminars (three sessions) (100 min/session)	Collaborative projects and group discussion: - The teacher organizes the work teams and assigns the topics. - The teams prepare their projects. - Each team makes an exhibition of their project in class (which is attended by all pre-service teachers). - There is a group discussion on the topics addressed.
Practices (five sessions) (120 min/session)	**Online digestive system animations**: Pre-service teachers watched various online digestive system animations (e.g., https://www.youtube.com/watch?v=4dG2PYD94es) & answered questions about mechanical & chemical digestion, peristalsis, gastric secretion, absorption, excretion, etc.
	Group experiments: Pre-service teachers, distributed in groups of no more than five individuals, were asked to make a model of one of anatomical structures that make up digestive system. For example, one group made a model of the liver using brown clay to create the lobes, blue modelling foam to create the inferior vena cava & the portal vein, red foam to make the proper hepatic artery and green foam to make the gallbladder. Each group was asked to explain the role played by the anatomical structure they had chosen within the digestive system.
	Biomathematical problems: Pre-service teachers, for example, were asked to describe digestion & metabolism of carbohydrates, fats, & proteins. Pre-service teachers were then asked to draw a schematic diagram of how these macromolecules are broken down & absorbed into the body.
	Conceptual/prediction questions: Pre-service teachers were given a worksheet with a description of a process (diagram or illustration) & a series of questions to answer, working with their peers. For example, pre-service teachers compared process of mechanical & chemical digestion. They were then asked to correlate these processes with bolus, chyme, & chyle.
	Clicker questions: Pre-service teachers were presented with a clicker question with multiple-choice responses. Pre-service teachers were encouraged to discuss ideas with their nearest peers & vote on the best response. For example, pre-service teachers were asked to predict which of the organs (from a list) are present in the digestive system and which are not.

APPENDIX B: QUESTIONS INCLUDED IN THE CONCEPTUAL TEST

1. Can you explain what digestion is?

2. Can you identify in the following figure the structures or organs that are part of the digestive system?



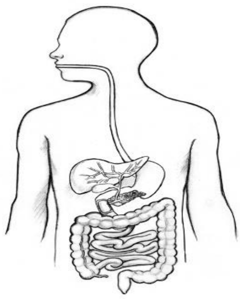
3. Can you explain the difference between mechanical and chemical digestion?

4. Can you explain the mechanical digestion processes?

5. Can you indicate the correct option for each of these processes? (you can choose more than one option):
6. Can you explain the digestive functions of saliva? (List all the functions you know)

Mechanical digestion takes place in:	Chemical digestion takes place in:
a) The entire digestive system	a) The entire digestive system
b) Only in the mouth	b) Only in the mouth
c) Only in the stomach and intestines	c) Only in the stomach and intestines

7. Can you color the food bolus, chyme and chyle path?



8. Can you explain the nutrient absorption process?

9. Can you explain, from a biological point of view, why lactose-intolerant people cannot eat foods that contain this sugar?

10. Can you indicate the benefits of a diet rich in fiber? (list all the benefits you know):

APPENDIX C

Table C1. Examples of answers mentioned by science pre-service teachers within each category

No	C1	Answer
1	I	*'Digestion is the process by which food is broken down into simple chemical compounds'.* *'Digestion is the complex process of turning the food you eat into nutrients.'*
	C	*'Digestion is the catabolic process in the digestive tract where ingested food is converted into simpler, soluble and diffusible substances that can be assimilated by the body.'*
	E	*'Digestion is the process of mechanically and enzymatically breaking down food into substances for absorption into the bloodstream. This process includes six activities: ingestion; propulsion; mechanical or physical digestion; chemical digestion; absorption; and defecation. The first of these processes, ingestion, refers to the entry of food into the alimentary canal through the mouth. There, the food is chewed and mixed with saliva, which contains enzymes that begin breaking down the carbohydrates in the food plus some lipid digestion via lingual lipase. Food leaves the mouth when the tongue and pharyngeal muscles propel it into the esophagus. This act of swallowing is an example of propulsion, which refers to the movement of food through the digestive tract. It includes both the voluntary process of swallowing and the involuntary process of peristalsis, which consists of sequential, alternating waves of contraction and relaxation of alimentary wall smooth muscles, which act to propel food along. Digestion includes both mechanical and chemical processes. Mechanical digestion is a purely physical process that does not change the chemical nature of the food. It includes mastication or chewing (mouth), mechanical churning (stomach), segmentation (small intestine), etc. In chemical digestion, starting in the mouth, digestive secretions (enzymes, acids, salts, water) break down complex food molecules into their chemical building blocks. Then, in the process of absorption, which takes place primarily within the small intestine, most nutrients are absorbed from the lumen of the alimentary canal into the bloodstream through the epithelial cells that make up the mucosa. Finally, in defecation, undigested materials are removed from the body as faces.'*
3	I	*'Mechanical digestion is a process occurring only in the mouth and involves breaking down food with the teeth.'* *'Chemical digestion is a process occurring only in the stomach and involves breaking down food by gastric juices.'*
	C	*'The main difference between mechanical and chemical digestion is that mechanical digestion refers to the process of physical breakdown of foods into smaller particles while chemical digestion refers to the process of chemical breakdown of foods especially by the enzymes into smaller substances that can be absorbed by the cells.'*
	E	*'Mechanical digestion is a relatively simple process that involves the physical breakdown of food into smaller fragments but does not alter its chemical make-up. It includes the acts of chewing (mouth), churning (stomach) and segmentation (small intestine). Peristalsis is also part of mechanical digestion. Chemical digestion, however, involves the catalytic processing of food in the gastrointestinal tract by digestive enzymes (amylase, lipase, protease, lactase, maltase, peptidase, sucrase, etc.), aided by co-secreted substances, required to break down the food substances (carbohydrates, proteins, fats, nucleic acids) into simpler molecules for absorption.'*
4	I	*'Mastication (chewing) is the only mechanical process of digestion, in which food is crushed & mixed with saliva to form a bolus for swallowing.'* *'There is only one process of mechanical digestion, chewing, a sensory-motor activity aimed at preparation of food for swallowing.'*
	C	*'Mechanical digestion includes mastication (process by which food is crushed and ground by teeth), churning (the stomach lining contains muscles which physically squeeze and mix the food with digestive juices) and segmentation (localized contractions of the muscularis layer of the alimentary canal, mainly in the small intestine, that move their contents back and forth while continuously subdividing, breaking up, and mixing the contents).'*
	E	*'Mechanical digestion starts with mastication (chewing) in the mouth. Teeth crush and grind large food particles into smaller pieces while saliva initiates the chemical breakdown of food. The slippery mass of partially broken-down food is called bolus, which moves down the digestive tract as you swallow (first voluntarily, but then involuntarily). As you swallow, the bolus is pushed from the mouth through the pharynx and into the esophagus. Peristalsis is the mechanism by which the food moves through the esophagus. The rhythmic contractions and relaxation of the segments of the longitudinal smooth muscles in the wall of the esophagus allow the unidirectional movement of the food through the alimentary canal. Mechanical digestion in the stomach occurs via peristaltic contractions of the smooth muscle from the fundus towards the contracted pylorus, termed "propulsion". Once the bolus is near the pylorus, the antrum functions to grind the material by forceful peristaltic contractions that force the bolus against a tightly constricted pylorus. The churning by the antrum serves to reduce the size of the food particles and is called grinding. Only particles smaller than 2 mm in diameter can pass through the contracted pylorus into the duodenum. The rest of the bolus is pushed back towards the body of the stomach for further mechanical and chemical digestion. This backward movement of the bolus from the pylorus to the body is termed retropulsion and also serves to aid in mechanical digestion. This sequence of propulsion, grinding and retropulsion repeats until the food particles are small enough to pass through the pylorus into the duodenum. In the small intestine, two different types of muscular contractions, called peristalsis and segmentation, move and mix the food. Similarly to what occurs in the esophagus and stomach, peristalsis is circular waves of smooth muscle contraction that propel food forward. Segmentation sloshes food back and forth in both directions promoting further mixing of the chyme.'*
6	I	*'The only digestive function of saliva is to moisten food so that it can be easily swallowed.'* *'Saliva is an aqueous fluid found in the oral cavity playing a fundamental role in the preservation and maintenance of oral health.'*

Table C1 (Continued). Examples of answers mentioned by science pre-service teachers within each category

No	C1	Answer
6	C	*'Saliva has multiple essential functions in relation to digestive process taking place in the upper parts of the gastrointestinal tract. Saliva acts in relation to taste, mastication, bolus formation, enzymatic digestion, and swallowing. The protective functions of saliva including maintenance of dental and mucosal integrity also indirectly influence the digestive process.'*
	E	*'Saliva plays a key role in taste perception because food particles need to be in solution to stimulate taste receptor cells in tastebuds within lingual papillae. Saliva also exerts several important actions in maintenance of tooth integrity (salivary clearance, buffer capacity, antimicrobial protective action, etc.) & increases masticatory performance promoting better breakdown of large food particles. During mastication food mixes with saliva to form a bolus. Water in saliva moistens food particles, whereas salivary mucins bind masticated food into a coherent & slippery bolus that can easily slide through the esophagus without damaging the oro-esophageal mucosa, improving both the frequency and efficiency of swallowing. In addition, saliva contains the enzyme a-amylase, or ptyalin, which is capable of breaking down carbohydrates (starch) into simpler sugars such as maltose and dextrin that can be further broken down in the small intestine. Another salivary digestive enzyme is lingual lipase, which breaks down a small fraction of dietary triglycerides in the oral cavity and stomach.'*
8	I	*'Nutrient absorption is the process through which the digested molecules of food are absorbed.'* *'The process of absorbing or assimilating nutrients'*
	C	*'Nutrient absorption is process which end products of digestion are absorbed into blood or lymph from intestinal mucosa.'*
	E	*'Absorption is the passage of nutrients through the intestinal walls into the blood. The primary site of absorption is the small intestine. The semi-liquid products of gastric digestion are released periodically into the duodenum, and then propelled downstream by peristaltic movements. The hydrolysis of proteins, triglycerides and starch continues within the duodenum and upper jejunum, under the influence of pancreatic enzymes. The final stages of hydrolysis of dietary macromolecules occur under the influence of extracellular enzymes at the mucosal surface. The small intestine is perfectly structured for maximizing nutrient absorption. The internal tissue of small intestine is covered in villi, which are tiny finger-like projections that are covered with even smaller projections, called microvilli. The digested nutrients pass through absorptive cells of the intestine via diffusion or special transport proteins. Amino acids, minerals, alcohol, water soluble vitamins, & monosaccharides (sugars like glucose) are transported from intestinal cells into capillaries, but the much larger emulsified fatty acids, fat-soluble vitamins, & other lipids are transported first through lymphatic vessels, which soon meet up with blood vessels.'*
9	I	*'Because lactose intolerance causes gastrointestinal symptoms, such as abdominal pain, bloating, diarrhea, gas, & nausea.'* *'People with lactose intolerance experience digestive problems eating dairy, which can have a negative effect on quality of life.'*
	C	*'Lactose intolerance is a digestive disorder caused by the inability to digest lactose, the main carbohydrate in dairy products. People with lactose intolerance don't make enough of the enzyme lactase, which is needed to digest lactose.'*
	E	*'Lactose intolerance is the clinical syndrome that occurs when the inability to digest lactose, a disaccharide molecule found in milk and dairy products, results in gastrointestinal symptoms. Normally upon the consumption of lactose, it is hydrolyzed into glucose and galactose by lactase enzyme, which is found in the small intestinal brush border. Deficiency of lactase, due to primary or secondary causes, results in the lactose not being able to be directly absorbed through the wall of the small intestine into the bloodstream, so it passes intact (unabsorbed lactose) into the colon. There, bacteria can metabolize lactose, and the resulting fermentation produces copious amounts of gas (a mixture of hydrogen, carbon dioxide, and methane) that causes the various abdominal symptoms (diarrhea, abdominal pain and bloating, nausea and vomiting, fullness, flatulence, etc.).'*
10	I	*'The only benefit of dietary fiber is to support gut health.'* *'Dietary fiber serves solely and exclusively to prevent or relieve constipation.'*
	C	*'A high-fiber diet supports gut health and digestion, improves cardiovascular health, helps weight management, reduces diabetes risk and strengthens the immune system.'*
	E	*'Dietary fiber intake provides many health benefits. Individuals with adequate intakes of dietary fiber appear to be at significantly lower risk for developing gastrointestinal diseases including gastroesophageal reflux disease, duodenal ulcer, diverticulitis, constipation, hemorrhoids, and colorectal cancer. This is due primarily to the ability of fiber to increase stool weight. The increased weight is due to the physical presence of the fiber, water held by the fiber, and increased bacterial mass from fermentation. Larger and softer stools increase the ease of defecation and reduce transit time through the intestinal tract, which may help to prevent or relieve above-mentioned diseases. An adequate fiber intake consistently lowers the risk of cardiovascular disease and coronary heart disease, primarily through a reduction in low-density lipoprotein levels. In addition, regularly consuming the recommended amount of fiber has the potential to attenuate glucose absorption rate, prevent weight gain, and increase the load of beneficial nutrients and antioxidants in the diet, all of which may help prevent type-II diabetes. Fiber may also provide a number of health benefits by altering the composition of the intestinal flora, including improvement in gut barrier function and host immunity, reduction of potentially pathogenic bacteria subpopulations and improved immune function via production of short-chain fatty acids production.*

Note. No: Task number; C1: category; I: Incorrect; C: Correct; & E: Excellent