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Flipped learning in a molecular biology course: pre-service teachers' performance and perceptions

Roberto Reinoso-Tapia[1], Sara Galindo[2], Jaime Delgado-Iglesias[3], Javier Bobo-Pinilla[4]

[1]*University of Valladolid, Spain, Corresponding author, roberto.reinoso@uva.es, ORCID ID: 0000-0003-0476-4975*
[2]*University of Valladolid, Spain, ORCID ID: 0000-0002-3184-2425*
[3]*University of Valladolid, Spain, ORCID ID: 0000-0001-8726-6976*
[4]*University of Valladolid, Spain, ORCID ID: 0000-0001-9600-2657*

ABSTRACT
The aim of this research was to evaluate and compare the efficiency of the flipped learning strategy with that of a conventional teaching method with respect to learning outcomes, cognitive gain, and perception and satisfaction with regard to the methodology used. The research was carried out during the 2021-2022 academic year and focused on a molecular biology course within a primary education Bachelor's degree programme, which included a total of 146 students. In order to assess the students' comprehension of the mechanisms involved in DNA replication, transcription and translation, we employed two different methods: the multiple-select Central Dogma Concept Inventory (CDCI) and a concept-mapping activity. A three-point Likert-type scale questionnaire was used to investigate the pre-service teachers' perceptions of the methodological approach that we used. The results show that the flipped learning pedagogical approach not only increases pre-service teacher's performance but also enables them to develop higher level cognitive skills than with traditional methodology. However, several features of the central dogma processes remained poorly understood, probably because of the multilevel and invisible nature of the molecular biology, and the lack of knowledge of the molecular interactions that facilitate these processes. The pre-service teachers had a more positive perception of the teaching approach and their own competence when they followed the flipped model.

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Introduction

The integration of Information and Communication Technology (ICT) into society, and particularly in the realm of education, has gained significant importance and advanced considerably in recent years. It has transitioned from being an optional resource to becoming an essential tool for teachers and students to effectively carry out their work (Courtney et al., 2022; Jurado et al., 2020; Starkey, 2020). These new technologies have allowed teachers to provide flexibility in learning and have opened up the possibility of developing new pedagogical proposals that encourage student interaction in a cooperative environment (Gómez-Fernández & Mediavilla, 2021; Sargent & Casey, 2020). The use of these tools has also had an impact on curricular content because they allow information to be presented in a very different way to traditional learning styles, which were much more focused on the lecture class and the use of the textbook. This new content is more dynamic. Its fundamental distinctive feature, interactivity, encourages the learners to have an active attitude as opposed to the passive nature of the traditional models. This makes it possible to involve the student more in their training (Cabellos et al., 2023; Harris, 2022; Jovanovi et al., 2017). Moreover, these emerging technologies have made it easier for learners to access information. Nevertheless, it is important to consider that modern students have grown up in a knowledge-based society marked by fast-paced technological advancements and an exponential growth in the amount of information disseminated via ICT. This unlimited and immediate access to information, together with the wide range of existing electronic devices, allows them to consult educational material at any time and at any place. Consequently, learners are able to set their own learning pace according to their personal characteristics, thus encouraging self-regulation of learning (Cassany & Sacristán, 2013; Chaves et al., 2016; Li & Zhu, 2023; Wilson, 2021).

Among the various existing educational models, the flipped learning methodology is gaining recognition and increasing in popularity due to its pedagogical efficiency and practicality in facilitating teaching and learning processes (Brady & Voronova, 2023; Fischer & Yang, 2022; He et al., 2016; Pozo-Sánchez et al., 2020; Zainuddin et al., 2019). This training modality is based on an active blended learning pedagogy in which the traditional roles of the classroom are inverted and where the student becomes the real protagonist (Bergmann & Sams, 2012). This allows the learner to initiate learning outside the traditional classroom by interacting with the content provided by the teacher. Students try to understand all of this information by themselves. If any doubt or difficulty arises, then they transfer online to consult with their teacher. Finally, and thanks to this feedback, the teacher can design practical or reflective activities for the students to use in class based on content that has been acquired in an autonomous way, thus developing a much deeper understanding of the subject matter. As a result, there is an increased utilisation of classroom time, and greater interaction among all participants involved in the educational process within the classroom (Basso-Aránguiz et al., 2018; Castellanos et al., 2017; Chiang, 2017; Förster et al., 2022; Hwang et al., 2015; Jia et al., 2021; Khadri, 2016; Prieto et al., 2021).

The literature extensively describes the effectiveness of the flipped learning methodology when compared to traditional learning styles that do not incorporate the use of technology. These benefits include increased student motivation (Al-Said et al., 2023; Hwang et al., 2020; Sánchez et al., 2017; Tse et al., 2019), greater use of the time spent in the classroom (El Miedany, 2019), greater self-regulation of learning (Cerezo et al., 2015; Hernández-Silva & Tecpan, 2017; Rivero-Guerra, 2018; Toivola et al., 2023), a high degree of commitment and responsibility (Cabero & Llorente, 2015; Candaş & Altun, 2023; Huang et al., 2018; López-Belmonte et al., 2019; Yilmaz, 2017), greater student participation (Chyr et al., 2017; Shek et al., 2023), the promotion of collaborative work (DeLozier & Rhodes, 2017; Tourón & Santiago, 2015), and the promotion of peer relationships and socialisation of the actors in the educational process (Báez & Clunie, 2019; Kwon & Woo, 2017; Lai, 2021).

Along with these advantages, the flipped learning methodology has a significantly positive impact on content acquisition and consequently, on the academic performance of students (Fisher et al., 2017; Karabulut et al., 2018; López-Núñez et al., 2020; Parati et al., 2023; Wagner et al., 2021). Many scholars have found that this type of methodological approach improves the academic performance of students when compared to those who follow a traditional methodology (Candaş & Altun, 2023; Hinojo et al., 2018; Huan, 2016; Huang et al., 2021; Jung et al., 2022; Li et al., 2022; Mendaña et al., 2017; Reinoso et al., 2021; Ristanto et al., 2022; Sola et al., 2019; Thai et al., 2017; Torrecilla, 2018). This is particularly evident when students engage in processes that demand greater cognitive effort, such as applying their knowledge to interpret novel situations, drawing comparisons, establishing cause-and-effect relationships, deducing conclusions, constructing arguments, making inferences, forming justified opinions, and even generating original ideas (Zainuddin & Halili, 2016). In traditional methodologies, the teacher takes the leading role in the educational action, with students having to resort to memorisation as the only learning plan (Mayorga & Madrid, 2010; Ortiz, 2013). The student is limited to memorising, retaining, and learning content individually. They are then subjected to specific assessment tests in the context of the closed classroom. However, they do not develop higher order cognitive skills, as is the case with the flipped learning approach (Hernández-Silva & Tecpan, 2017).

In summary, it seems clear that flipped learning methodology could be an excellent alternative to traditional teaching models. However, several studies have pointed out that the effectiveness of this approach varies depending on the educational level and subject area (Goedhart et al., 2019; Kashada et al., 2017). It is important to note that despite the crucial role that pre-service teachers play in imparting didactic knowledge and promoting scientific literacy among future generations, there is a dearth of empirical evidence on the impact of flipped classrooms on learning outcomes among pre-service teachers. This is particularly true when it comes to learning scientific content. Specifically, many authors agree that the discipline of molecular biology is difficult to learn (Duncan & Tseng, 2011; Newman et al., 2018; Southard et al., 2016). The intricate nature of the mechanisms involved, the constantly evolving knowledge base, and the technical jargon used in the subject matter create a challenging learning environment for students, and a daunting teaching task for instructors. This is the primary motivation that prompted us to propose the current study, which renders it especially pertinent and distinct from previously published research. To this end, the following research objectives have been set out:

1. To compare the academic achievement of pre-service teachers in the "Curricular Development of Experimental Sciences" subject (Molecular Biology section) of the Primary Education Bachelor's degree when utilising both traditional and flipped learning methodologies.

2. To determine whether the instructional model applied influences the students' cognitive skills.

3. To gauge the pre-service teachers' perception of the methodology used and the competences acquired.

With these objectives in mind, we have formulated the following research questions concerning the implementation of the flipped learning model within the realm of science education as part of the university training program for pre-service teachers:

- Does the academic performance of pre-service teachers improve with a flipped learning methodology when compared to the traditional approach?
- Does the flipped learning methodology allow pre-service teachers to develop skills at a higher cognitive level than with traditional methodology?
- Does the flipped learning model improve the pre-service teachers' attitudes towards the instructional methodology and help them to develop their competence as future teachers?

Methods

Study Design

This study was conducted using a quantitative research approach through a quasi-experimental research design, wherein an experimental group instructed with the flipped learning model was compared to a control group receiving traditional training practices. Therefore, the intervention modality is conceived as an independent variable in this research and the learning outcomes obtained by the students in its application are postulated as a dependent variable.

Participants

This study involved the participation of 146 undergraduate students from the Faculty of Education and Social Work at the University of Valladolid (Spain) who were enrolled in the primary education Bachelor's degree programme. Both participating groups (non-flipped and flipped) had similar characteristics in terms of the number of students and other socio-demographic variables (i.e., gender, age and pre-university education; see Table 1). For the selection of these subjects, a non-probabilistic convenience sample was used because of the ease of access to the students and their availability to carry out the research. The sample consisted of 91 females (62.3%) and 55 males (37.7%), whose ages ranged from 18-24 years = 89.5%; 25-30 years = 8.2%; >30 years = 2.3%). With regard to the pre-university training taken by the students to gain access to university, 28.8% came from the Baccalaureate in Science, while the rest (71.2%) came from the Baccalaureate in Humanities and Social Sciences.

Table 1

Characteristics of pre-service teachers participating in the non-flipped and flipped groups

	Non-flipped group	Flipped group	P value
Number of pre-service teachers	75	71	
Gender			
Female	46 (61%)	45 (63%)	0.643
Male	29 (39%)	26 (37%)	
Age (years)	22.5 ± 4.6	22.2 ± 4.4	0.179
Pre-university itinerary			
Science baccalaureate	22 (29%)	20 (28%)	0.587
Humanities baccalaureate	53 (71%)	51 (72%)	

Research Instrument

To measure academic performance, we considered the scores that were collected through two previously validated instruments (Newman et al., 2016; Southard et al., 2016).

• The first instrument was the Central Dogma Concept Inventory (CDCI) questionnaire, which is composed of 23 multiple-choice questions that are specifically designed to determine the students' knowledge of the essential concepts of the central dogma of molecular biology.

• The second instrument was a written test in which pre-service teachers had to devise a concept map of the flow of genetic information that takes place in humans using 15 standardised cellular and molecular terms. Although most of the pre-service teachers were already familiar with concept maps from their previous courses, a brief introduction was given before they started the activity to explain their main characteristics and the steps to be followed to elaborate it. We expressly asked the pre-service teachers to use linking words or phrases as connectors to link the ideas and/or concepts provided and explain the relationships. The following terms were chosen for the concept map: genetic information, inheritance, enzyme, mutation, protein, DNA, transcription, ribosome, genetic disease, nucleic acid, replication, gene, amino acid, translation, and RNA. Once the task was completed, the connections established between the terms provided were coded. This process was carried out independently by three lecturers from the department, with the presence of a fourth being required in the event of any discrepancy between the first three (which only occurred very sporadically). Type 3 concept maps were classified when the connections showed a relationship between terms based on function, mechanism, causality, or action. Type 2 maps were classified when the connections simply indicated a structural relationship (location, composition, etc.) or when the relationship between terms was based on a loose action or function. Finally, type 1 maps were classified when there was no connection between terms or when only the connecting arrow appeared without a descriptive word or phrase.

The researchers used a questionnaire with a three-point Likert scale (–¬1 = disagree, 0 = neutral, 1 = agree) to measure the pre-service teachers' perceptions of the instructional approach (Tang et al., 2017). The questionnaire included 14 closed questions divided into two sections. The first section

(Q1 to Q9) focused on the pre-service teachers' views on the instructional approach, while the second section (Q10 to Q14) focused on their perception of competence development.

All of the instruments that we used were translated into Spanish and validated following the same statistical procedures used by the authors. First, content validation was carried out by experts (5 judges) to ascertain the relevance and appropriateness of the items according to the objective of the study and taking into account the target audience. These experts provided a relevant assessment of the questionnaire and gave recommendations to improve the wording and interpretation of the items. In the second phase, a construct factor validation was carried out, which included an exploratory and descriptive item analysis and an exploratory factor analysis. We evaluated the questionnaire's reliability and internal consistency using Cronbach's alpha statistic (α = 0.81). The results of all the tests we performed demonstrated that the tools were valid and reliable for use with the Spanish population.

Procedure and Data Analysis

The research was conducted during the 2021-2022 academic year. The participation of the pre-service teachers was voluntary, with all of them signing an informed consent form.

The study was conducted in the setting of the mandatory course "Curricular Development of Experimental Sciences" in the second year of the primary education Bachelor’s degree, which is worth 6.0 European Credit Transfer System (ECTS) credits. The course specifically focused on Block III, which covers the theoretical and practical aspects of the biology content in the primary education curriculum and its didactics. The portion of the subject related to this study has a total workload of 3.0 ECTS credits, out of which 2.0 ECTS credits are dedicated to the theoretical content, equivalent to 10 classroom sessions of two hours each; and 1.0 ECTS credit is assigned to the practical part, consisting of two laboratory sessions (genomic DNA extraction and protein quantification) of two hours each and three classroom practice sessions (exercises on replication, transcription, and translation) of two hours each. The section of the biology subject that was selected for this study is focused on molecular biology, which covers fundamental concepts related to the composition, structure, and function of nucleic acids, the human genome, the transmission of genetic information, the genetic code, and protein synthesis.

Once the sample had been drawn up, the study groups (control and experimental) were randomly configured. In both groups, the distribution of the theoretical and practical blocks, the content, the teaching staff involved, the assessment and grading criteria and the evaluation tools were the same. The only difference between the two groups was due to the intervention modality—a traditional training process was used in the control group and an inverted-learning model was used in the experimental group.

In the control group, the pre-service teachers were taught using traditional teaching methods, which included lectures and practical classes (in both the laboratory and classroom). During these classes, the teacher delivered the theoretical content and led the activities. The pre-service teachers attended classes in person and the teacher did not use pre-recorded videos or require them to watch any audio-visual materials before coming to class. To help the students keep track of the course, they were provided access to a digital platform where all the course materials such as multimedia presentations, lab instructions, practical exercises, etc. were uploaded by the instructor after each class. The students were encouraged to review the material before attempting their assignments to reinforce their understanding. The students in the control group were required to complete homework assignments after each lesson. The pre-service teachers were instructed to submit their completed assignments within one week after the lesson, and they received feedback from the teacher. The instructor provided answers to each question, and if the pre-service teachers encountered difficulties, they could ask for assistance.

The experimental group in this study adopted a flipped learning methodology, which had the same schedule as the control group. The pre-service teachers in this group had access to the same virtual space as the control group, but with the addition of pre-recorded material such as video lectures, flash simulations, and interactive tutorials. They were expected to review this material before attending class. In addition, technological applications with a didactic component were used to reinforce the assimilation of the content. The teachers responsible for teaching the subject selected and created the flipped material using various computer programs and free access platforms. For instance, they used Kaltura software to develop asynchronous video lessons. Additionally, they utilised eduCanon to enhance the interactive and engaging nature of the videos, by adding questions that pre-service teachers could answer to receive immediate feedback based on their responses. This tool meant that the pre-service teachers in this group came to the face-to-face sessions having previously worked on the content of the topic because the videos were prepared so that questions could not be omitted, thus encouraging the active participation of the pre-service teachers. After the pre-service teachers had completed their individualised work, they were provided with online questionnaires to review the theoretical content that they had worked on and provide the teacher with information on the difficulties encountered before their arrival in the classroom, which were immediately resolved at the beginning of the class. This allowed more classroom time to be devoted to other activities that promote active learning (e.g., discussion of case studies, collaborative work, analysis and synthesis activities, reflection activities, debates, problem solving, etc.; see Table 2). More detailed examples of classroom activities used in the flipped sections are presented in appendix 1.

Table 2

Classroom activities used in the flipped sections

Activity	Description
Analysis and synthesis activities	The teacher provides pre-service teachers with several scientific articles related to the central dogma of molecular biology and asks them to try to make an outline to organise and synthesise the most relevant or significant aspects that appear.
Research or problem-solving activities	The teacher presents a case study related to a specific genetic disease and asks the pre-service teachers to investigate the possible cause of the disease.
Interaction and communication activities	In class, the teacher raises a number of ethical questions about the genetic manipulation of embryos and invites pre-service teachers to discuss the pros and cons of this technique.
Collaborative knowledge building activities	The teacher is responsible for arranging the groups and selecting the topics for the activities. After completing their projects, groups present their work in class, followed by a discussion.
Reflection activities	The teacher invites the pre-service teachers to reflect on the importance of the Human Genome Project.

Once all of the content had been taught, the subject teachers distributed the questionnaires, as well as the instructions for drawing up the concept map to all of the pre-service teachers participating in the study (i.e., experimental group and control group). Both tasks were completed by the pre-service teachers in online format and sent to the teachers through the Moodle virtual platform.

The data was analysed using the SPSS v.26 software (IBM Corp., 2019), and basic descriptive measures such as mean and standard deviation were calculated. To compare the means between the experimental and control groups (independent samples), either Student's *t*-test or the non-parametric Mann-Whitney U test was used depending on the Normal or non-Normal distributions. In all statistical analyses, p-values less than 0.05 were considered statistically significant.

Findings

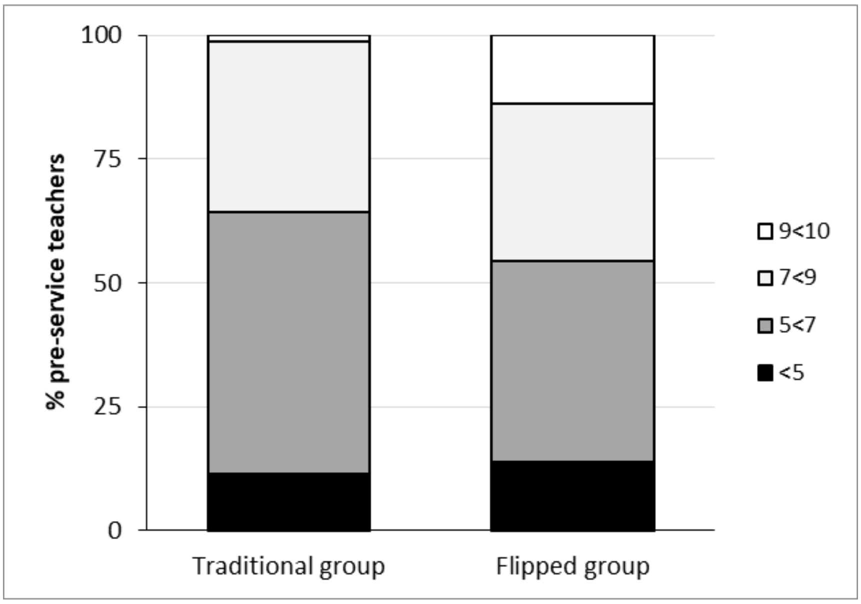
Performance Evaluation

In the first exercise, the CDCI questionnaire, the control group pre-service teachers had an average score of 6.4 ± 1.4, while the experimental group had an average score of 6.7 ± 2.1. Figure 1 shows that the majority of pre-service teachers in both groups scored between 5 and 7, with 52.9% in the control group and 40.6% in the experimental group, followed by those who scored between 7 and 9, with 34.3% in the control group and 31.7% in the experimental group. Nonetheless, it was observed that the experimental group had a significantly higher percentage of pre-service teachers (13.9%) who scored above 9 in the CDCI questionnaire, compared to the control group (1.4%).

The questions that received the highest scores were those that dealt with the structure of biomolecular building blocks (such as nucleotides) and the structure of macromolecular products (such as RNA). On the other hand, questions that required a higher level of understanding, such as those related to the relationship between biomolecule structure and function, as well as molecular interactions that facilitate the processes of the central dogma (such as DNA replication, transcription, and translation), were more difficult, especially for pre-service teachers in the control group. The statistical analysis did not reveal any significant differences in scores based on gender, age, or pre-university education.

Figure 1

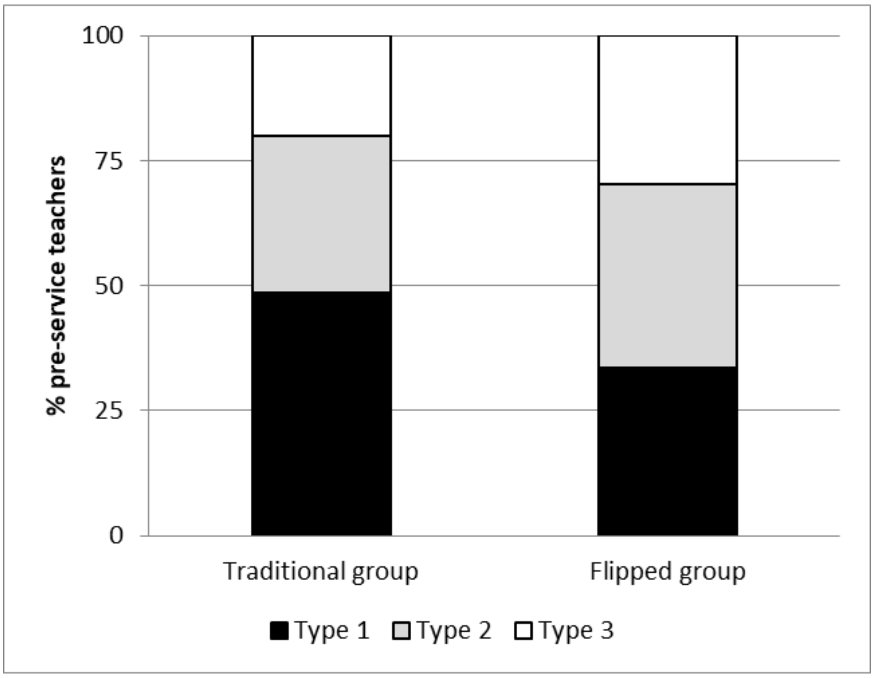
Scores obtained by the control group (traditional group; tg) and the experimental group (flipped group; fg) in the cdci questionnaire



The differences between the experimental group and the control group were more noticeable in the second exercise (concept mapping). Figure 2 shows that almost half of the pre-service teachers in the control group were not able to make any connections between the given terms or even link the terms with an arrow (type 1), indicating a lack of understanding of the central dogma of molecular biology and the processes involved in the transmission of genetic information. On the other hand, in the experimental group, only one-third of the participating students achieved this lower level of concept map coding ($p < 0.05$). The study revealed that the differences between the experimental group and the control group were also observed in the type 3 concept maps, which demonstrated a good understanding of the mechanisms that control the flow of genetic information. The results showed that 29.7% of the pre-service teachers in the experimental group were able to establish causal and/or functional relationships between the terms provided (type 3), while only 20.0% of the group that followed the traditional methodology were able to do so. It is noteworthy that in this second exercise, there were no significant differences in the scores based on gender, age or pre-university education (See appendix 2 for an example of concept maps from representative cases of the three different types).

Figure 2

Concept map connections made by the control group (traditional group; tg) and the experimental group (flipped group; fg) that were coded as functional/mechanistic (type 3); vague, structural, or categorizing (type 2); or associative or blank (type 1)



Pre-service Teachers' Perspectives and Self-perceived Competence

The study found that pre-service teachers in the experimental group scored significantly higher than those in the traditional group on the questions related to their perspectives (6.15 ± 2.53 vs. 3.25 ± 2.77, $p<0.0001$). Specifically, over 75% of the pre-service teachers in the flipped group agreed that this method of teaching had helped them improve their motivation towards learning the subject matter (Q1). This level of motivation was in stark contrast to that of the pre-service teachers who followed the traditional model, which barely exceeded 30% ($p < 0.001$). Over 80% of pre-service teachers who participated in the flipped learning model agreed that it was helpful and aided in their understanding of the subject matter, as compared to only 58% of those who followed the traditional model. This difference was statistically significant with a p-value less than 0.05 (Q2). The study found that there was a significant difference of more than 25% between the experimental group and the control group when pre-service teachers were asked if the teaching model had helped them to prepare well for the final examination of the subject (Q3). More than 83.1% of the pre-service teachers in the experimental group agreed with this statement, compared to 57.3% in the control group ($p < 0.05$). In terms of satisfaction, there were noticeable differences between the two groups of pre-service teachers. Those who followed the flipped method expressed greater satisfaction with the subject compared to those who followed the traditional methodology (Q4). These differences were also seen in the response to the question about whether they liked the teaching method (Q5), where the difference was more than 20% between the two groups (85.9% vs. 64.0%, $p < 0.05$). Although the pre-service teachers expressed a high level of satisfaction with the flipped methodology, there were no significant differences between the two teaching methods when they were asked if they would like this approach to be implemented in other courses within their degree program (Q6). It is possible that one of the reasons could be the increased workload and daily effort required for working with this methodology compared to the traditional model. This was suggested by the responses to questions Q7-Q9 in the questionnaire.

The study showed significant differences in the perceived competence development between the pre-service teachers who followed the flipped model and those who followed the traditional model. The experimental group had a higher score (3.07 ± 2.11) compared to the control group (1.35 ± 1.87, $p < 0.0001$). The pre-service teachers who followed the flipped model reported that this methodology helped them to improve their competence in linguistic communication (Q10 and Q11), learning to learn competence (Q12), and science competence (Q13 and Q14) more than those who followed the traditional model ($p < 0.05$). These differences exceeded 20% between the two groups.

Discussion

The flipped learning model is widely regarded as one of the most effective active teaching methods, as it places the student at the centre of their own learning and positions the teacher as a facilitator of the learning process (Ishartono et al., 2022; Zainuddin et al., 2019). This approach emphasises the active participation of students through collaborative work, problem-solving in the classroom, and the use of case studies, while leaving activities such as reading textbooks, watching presentations and videos, and listening to recordings for students to complete outside of class (Thai et al., 2017). These teaching strategies not only improve the students' learning standards but also reduce obstacles and difficulties in understanding curricular content, especially in those disciplines considered difficult to learn, such as molecular biology (Wood-Robinson et al., 2000).

To the best of our knowledge, this study is the first attempt to investigate the impact of incorporating a flipped learning approach to teaching molecular biology in the context of a Bachelor's degree in primary education. The findings of this research demonstrate that the flipped learning methodology enhances the academic performance of students when compared to the traditional approach. These results are consistent with recent studies (Awidi & Paynter, 2019; Barral et al., 2018; Dehghanzadeh & Jafaraghaee, 2018; Hinojo et al., 2018; Juan-Llamas, 2023; Matzumura et al., 2018; Ristanto et al., 2022; Shen & Chang, 2023) and with most of the meta-analyses conducted on this subject (Bredow et al., 2021; Cheng et al., 2018; Galindo-Domínguez & Bezanilla, 2019; Gong et al., 2023; Hew et al., 2021; Hew & Lo, 2018; Hu et al., 2018; Kang, 2018). Furthermore, they align with the results reported by various researchers in a similar educational context to ours (i.e., university degrees linked to initial teacher training). An example of this is a study conducted by Jeong et al. (2018) with pre-service teachers in a primary education Bachelor's degree programme, similar to the context of our study, where the flipped classroom model was found to be more effective than the traditional teaching format, resulting in a difference of over two points on the test between the two groups. Similarly, González-Gómez et al. (2017) found in a previous study with the same group of students that the percentage of students who passed the subject increased by over 10% with this new teaching model. Candaş and Altun (2023) also reported significant differences in academic performance, with the flipped learning approach showing better outcomes than the traditional methodology. These findings demonstrate that the flipped learning methodology improves the learning outcomes of university students in experimental science.

Another remarkable aspect of this research, if we take into account Bloom's taxonomy (Churches, 2020), is that the flipped learning model allows students to acquire cognitive skills at a higher level than with traditional methodology. In a traditional classroom, most of the teacher's time is taken up with explaining subject matter and seeking to make the student remember, memorise and understand it individually. These skills correspond to the lowest levels of cognitive work and are carried out in class (group space) through direct teaching by the teacher. It is in autonomous work at home (individual space), without the teacher being there to help them, where students, through exercises, projects, and so on, transfer information into knowledge, thus reaching higher levels of complexity in learning (i.e., higher order skills such as applying, analysing, evaluating and creating; Santiago & Bergmann, 2018). On the other hand, the flipped learning approach presents basic content information to students in a more engaging manner, which is primarily related to levels such as remembering or understanding, allowing them to work on it independently. Meanwhile, more challenging learning, from a cognitive perspective, is done with the guidance of the teacher and peers in the group setting. This reversal of roles enables the classroom to become a lively and interactive learning environment, with the teacher guiding the students on how to apply the concepts they have learned and engaging them creatively with the subject matter (Santiago, 2020).

As mentioned earlier, our findings support the notion that the flipped learning method enhances the learning outcomes of pre-service teachers compared to the traditional method. However, some aspects of molecular biology's central dogma, such as the molecular processes and mechanisms that drive genetic information flow, still pose a challenge to many students. This could be due to the difficulty that students face in incorporating and utilizing the molecular and submicroscopic scale when dealing with complex concepts related to the central dogma, as has been previously noted by other researchers (Duncan and Reiser, 2007; Newman et al., 2012). The difficulty in understanding the central dogma of molecular biology, particularly the molecular processes and mechanisms that drive genetic information flow, could be attributed to the complex multilevel nature of the phenomena in molecular biology. This complexity arises from the different levels of organisation involved, including submolecular, molecular, subcellular, and cellular levels, and the lack of knowledge of the interactions between them. To understand these mechanisms, students need to recognise specific entities involved, their activities created by interactions, and the temporal and spatial interactions and organisation of these molecules, which create functional units that lead to biological phenomena (Hartwell et al., 1999; Machamer et al., 2000; Russ et al., 2008; Van Mil et al., 2013). Our findings support this idea, as many of the pre-service teachers in our study were able to identify some of the molecular entities involved in genetic information flow and recognise terms such as "transcription" and "translation," but struggled to understand the molecular interactions that underpin these processes. As a result, they developed incomplete or fragmented mental models of the Central Dogma. Their descriptions often contained gaps, errors in identifying the appropriate entities, poorly defined boundaries between mechanisms, and a lack of understanding of the overall function of the mechanisms. According to Southard et al. (2016), to develop more integrated knowledge, students must use functional and causal drivers as organizing principles to construct a cohesive network of biological concepts.

The third aim of this study was to investigate if the use of the flipped model had an impact on pre-service teachers' perceptions of the instructional methodology and molecular biology concepts, as well as their self-perceived competence in teaching. Our findings indicate that pre-service teachers in the flipped group had higher scores than those in the traditional model on both questions related to perspectives and self-perceived competence. These results are consistent with recent studies (Espada et al., 2020; Monjaras-Salvo et al., 2022; Ros & Rodríguez-Laguna, 2021; Sánchez-Rivas et al., 2019). In subjects that are complex and have a high scientific load, such as molecular biology in our case, the traditional teaching methodology can lead to demotivation and negative attitudes towards learning. Therefore, new pedagogical models are needed to improve the learning outcomes and promote positive emotions and attitudes towards learning. The flipped learning approach has been shown to help students develop a positive attitude towards learning, which leads to increased motivation, awareness of the learning process, and a higher degree of involvement and autonomy. This approach is especially effective for students who are accustomed to traditional teaching methods. Studies have demonstrated the benefits of flipped learning in terms of student motivation and engagement (Candaş & Altun, 2023; El Miedany, 2019; Hwang et al., 2020; Lee et al., 2018; Tse et al., 2019).

Despite the many benefits reported by our students regarding the flipped learning approach, it is important to note their reluctance to apply this model to other subjects. One possible reason is the increased workload involved in using this methodology, not only due to the preparation required for classes and activities, but also because this new model demands much more autonomous learning than students are accustomed to with traditional teaching methods (Kim, 2018; Ros & Rodríguez-Laguna, 2021). The flipped learning approach, like any other non-traditional learning method, requires a significant change in students' mindsets and study habits, which must be gradually implemented to allow for adaptation without perceiving it as an overwhelming effort.

According to the students' perception, the flipped methodology improves the development of certain skills necessary for achieving the educational objectives at the primary education level and for their future career as teachers. Compared to the traditional methodology, the flipped approach helps students acquire and apply scientific knowledge to understand the physical world, develop skills and attitudes that facilitate the exploration of natural phenomena, and analyse them ethically and responsibly to solve problems in the field of experimental sciences. This is especially important for teaching and learning experimental sciences. In addition, it is important that students are able to effectively convert their scientific knowledge, specifically related to molecular biology, into teachable knowledge through appropriate processes of didactic transposition. Throughout this process, it is crucial to continually monitor the progress of both the students and the teaching and learning process itself. Hidalgo et al. (2021) suggest that the traditional teaching approach, which primarily focuses on delivering content and where the teacher holds a dominant position in the classroom, has several shortcomings that hinder students from developing necessary competencies. The authors propose a shift towards more active teaching methodologies, such as the flipped learning model, which empowers students to take a leading role in their own learning process and fosters a higher level of engagement and independence, ultimately promoting scientific and critical thinking as a fundamental skill for cognitive development (Hernández et al., 2019; Salas-Rueda & Lugo-García, 2018). The flipped learning model enables students to develop skills in critical thinking, information management, synthesis, writing, and argumentation, among others. Through this approach, students can reflect on real-world problems, identify and formulate research questions, plan and execute research projects, and report their findings (González & Huerta, 2019; Tapia et al., 2018). Additionally, the flipped model promotes collaborative work and peer learning experiences while also facilitating communication skills through interactions between students and teachers in virtual spaces (Hernández-Silva & Tecpán, 2017; Lakkala et al., 2023; Lu et al., 2023; Tourón & Santiago, 2015).

Conclusion and Implications

The findings of this study demonstrate the advantages that the flipped learning approach brings to the process of teaching and learning molecular biology for future teachers. In relation to the first research question (Does the academic performance of pre-service teachers improve with a flipped learning methodology when compared to the traditional approach?), it is concluded that there is a significant improvement in the learning carried out by students when a flipped instruction methodology is followed. In relation to the second research question (Does the flipped learning methodology allow pre-service teachers to develop skills at a higher cognitive level than with traditional methodology?), it is concluded that the flipped learning model allows students to perform activities that develop higher order cognitive categories according to Bloom's taxonomy. Finally, and addressing the third research question (Does the flipped learning model improve the pre-service teachers' attitudes towards the instructional methodology and help them to develop their competence as future teachers?), it is concluded that pre-service teachers have a more positive opinion towards this type of methodology and a better perception of the competences acquired during their learning experience.

The main focus of this research is to provide the scientific community with further information about the use of the flipped learning approach with university students studying for a Bachelor's degree in primary education. Additionally, the study aims to showcase the advantages of incorporating this type of active teaching methodology in the learning process of experimental sciences to the educational community. This is a key aspect if we consider that these students will have the difficult task of encouraging children's interest in science and technology. Among the limitations of the study is the fact that a non-probabilistic sampling method was applied. This implies that the findings obtained in this study should be approached with caution, especially when attempting to apply them to other contexts. Additionally, the subject matter being taught may have impacted students' satisfaction with the flipped learning approach. If the content is engaging and relevant to students' interests and motivations, it may lead to greater satisfaction with the teaching method. Despite the complexity of the subject matter, such as the central dogma of molecular biology, students' overall perception of the flipped learning approach was satisfactory in this study. Moving forward, the researchers plan to expand the use of this teaching methodology to other experimental science subjects and training programmes for teachers, including Bachelor's programmes in early childhood education and Master's programmes in secondary education.

Disclosure Statement

The authors report there are no competing interests to declare.

Ethical Statement

This 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). All students voluntarily agreed to participate in the study by signing the informed consent form.
- 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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Appendix 1

Examples of Classroom Activities Used in the Flipped Sections

Analysis and synthesis activities

- The teacher briefly explains the typical structure of a scientific article and instructs students to individually read the article entitled 'DNA→RNA: What do students think the arrow means? (Wright et al., 2014)' for 20 minutes.
- Students are asked to underline or take notes on key elements, such as the research problem, topics mentioned, methods used, results obtained, and conclusions.
- Following the reading, the teacher requests students to highlight what they have learned, attempt to create an outline to organize their ideas, and identify any confusing aspects or questions they may have about the content.

Research or problem-solving activities

- The teacher presents a case study on "Cystic Fibrosis".
- Task for pre-service teachers:
    - Research the genetic basis of Cystic Fibrosis: Identify the CFTR gene as the key gene associated with the disorder and understand how mutations in this gene lead to the development of Cystic Fibrosis.
    - Explore the inheritance pattern of Cystic Fibrosis, which follows an autosomal recessive pattern: Understand how individuals need to inherit two mutated copies of the CFTR gene (one from each parent) to develop the disease.
    - Examine the clinical manifestations of Cystic Fibrosis: Understand how the dysfunction of the CFTR protein contributes to these symptoms.
    - Research diagnostic and screening methods for Cystic Fibrosis, including newborn screening and genetic testing: Discuss the importance of early detection for better management and treatment.

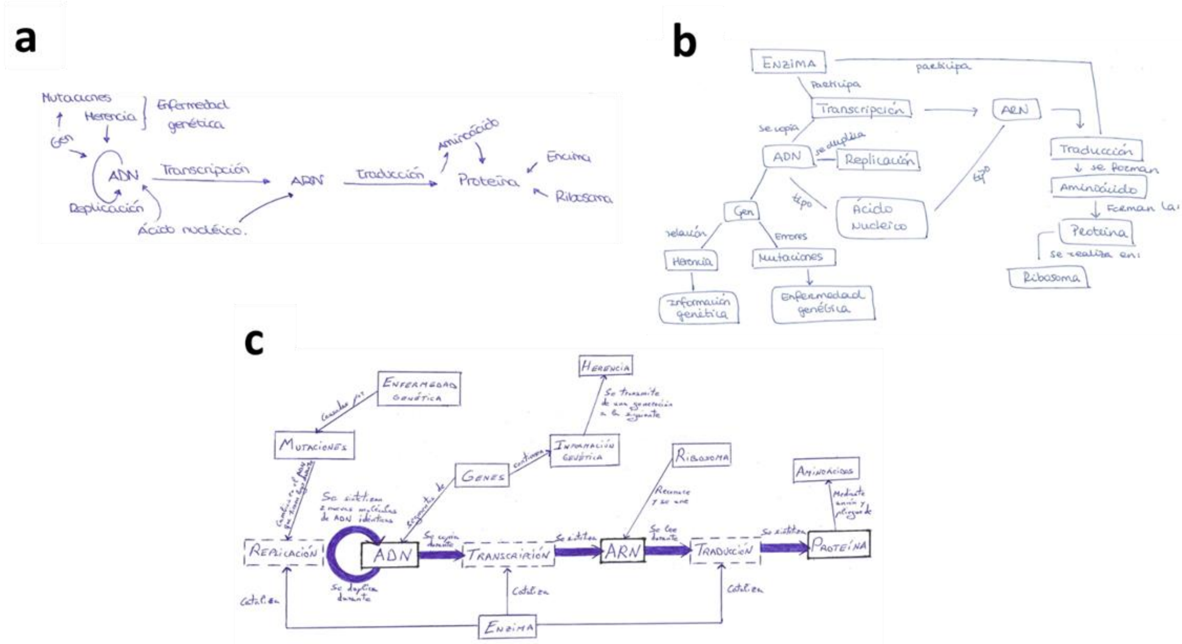
Interaction and communication activities

- The teacher raises a series of ethical questions related to the genetic manipulation of embryos, specifically a cutting-edge technique known as CRISPR-Cas9, which allows scientists to modify genes with unprecedented precision.
- The teacher divides the class into small groups and assign each group a specific role related to the genetic manipulation of embryos (scientists, ethicists, parents, policymakers, individuals with genetic disorders, etc.).
- Each group will be responsible for preparing a short presentation representing their assigned role's perspective on genetic manipulation.
- The teacher prompts pre-service teachers to engage in a discussion about the ethical considerations surrounding this technology, supported by evidence and arguments.
- After the panel discussions, the teacher allows students to ask questions, challenge perspectives, and engage in a respectful exchange of ideas.

Collaborative knowledge building activities
- The teacher assigns a project to help students visually understand the structural differences between DNA and RNA. The class is divided into two groups, each tasked with constructing a three-dimensional model—one focused on DNA and the other on RNA. • The DNA group uses materials such as coloured pipe cleaners for the sugar-phosphate backbone, different coloured beads for nitrogenous bases and toothpicks to represent hydrogen bonds between base pairs. The group carefully constructs a double helix to represent the structure of DNA, ensuring accurate pairing of complementary bases. • The RNA group utilizes materials such as pipe cleaners for the single-stranded sugar-phosphate backbone, colored beads for nitrogenous bases and toothpicks to represent hydrogen bonding. The RNA group creates a single-stranded model, emphasizing the presence of uracil instead of thymine in RNA. - After a designated period, both groups present their completed models to the class. - Following the presentations, the class engages in a discussion to compare and contrast the two nucleic acids (structural and functional differences)
Reflection activities
- The teacher provides a brief overview of the Human Genome Project and poses reflective prompts such as: • Why do you think the Human Genome Project is considered a landmark in scientific research? • How might the knowledge gained from the Human Genome Project impact medical practices and advancements? • How do you foresee the knowledge gained from the Human Genome Project impacting your future role as an educator? • In what ways might you incorporate genomics-related topics into your future classroom activities? - The teacher forms small discussion groups and ask participants to share their reflections within their groups. - Finally, the teacher facilitates a whole-class discussion where groups can share key insights and observations from their discussions.

Appendix 2

Examples of Pre-service Teachers' Concept Maps of (a) Type 1, (b) Type 2 and (c) Type 3



Note. *Captions read: Ácido nucleico=nucleic acid, ADN=DNA, replicación=replication, transcripción=transcription, ARN=RNA, traducción=translation, aminoácido=amino acid, proteína=protein, enzima=enzyme, ribosoma=ribosome, gen=gene, herencia=inheritance, mutaciones=mutations, enfermedad genética=genetic disease, información genética=genetic information, participa=participates, se copia durante=is copied during, se duplica durante=is duplicated during, tipo=type, relación=relation, errores=errors, se forman=are formed, forman la=form the, se realiza en= takes place in, cataliza=catalyzes, se sintetiza=is synthesised (DNA, RNA and protein), causadas por=caused by, cambios en el ADN que tienen lugar durante= changes in the DNA sequence during, segmentos de=segments of, contienen=contain, se transmite de una generación a la siguiente=is passed from one generation to the next, se lee=is read during, reconoce y se une=recognises and binds to, mediante union y pliegue de= by binding and folding of).*