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# Impact of active learning strategies on future physics teachers' disciplinary knowledge in a didactic course

# Impacto de estrategias de aprendizaje activo sobre el conocimiento disciplinar de futuros profesores de física, en un curso de didáctica

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## Abstract

This article presents characteristics and results of a methodological intervention implemented in classes of a didactic course for initial training of physics teachers in a Chilean public university. The intervention consisted of teaching pre-service teachers about active learning strategies which they then used to design and conduct physics classes to their classmates. In order to measure the impact of the intervention on the level of disciplinary knowledge of future teachers, the Force Conceptual Inventory (FCI) was employed in pre and post instruction modality. The results show a normalized gain of 0.40 at the end of the intervention, suggesting that future physics teachers improved their level of conceptual understanding of disciplinary content after having learned and applied active learning strategies to teach peers. Implications for teacher training and study limitations are discussed by the authors.

***Keywords***: active learning, initial teacher training, physics, didacticism

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## Resumen

En este artículo se presentan características y resultados de una intervención metodológica implementada en clases de un curso de didáctica para formación inicial de profesores de física, en una universidad estatal chilena. La intervención consistió en enseñar a los estudiantes algunas estrategias de aprendizaje activo que luego utilizaron para diseñar y ejecutar clases de física frente a sus pares. Con el fin de medir el impacto de la intervención sobre el nivel de conocimiento disciplinar de los futuros profesores, se utilizó el Inventario sobre Conceptos de Fuerza (FCI, por su sigla en inglés) en modalidad pre y post instrucción. Los resultados muestran una ganancia normalizada de 0,40 al finalizar la intervención, lo que sugiere que los futuros profesores de física mejoraron su nivel de entendimiento conceptual sobre el contenido disciplinar después de haber aprendido y aplicado estrategias de aprendizaje activo para enseñar a sus pares. Se discuten implicancias para la formación docente y limitaciones del estudio.

***Palabras clave***: aprendizaje activo, formación inicial de profesores, física, didáctica

In recent decades it has been a priority in Chile to implement a wide range of initiatives to improve education quality, including strengthening the teaching profession (Sisto, 2011) and institutional improvement of initial training programs (OAS, 2008). These initial teacher training programs have been identified as having a certain amount of disarticulation between courses in the pedagogical area and those focused on the specialty or subject (Cofré, Camacho, Galaz, Jiménez, Santibáñez, & Vergara, 2010; MINEDUC, 2005). Likewise, questions have been raised about the pedagogical model commonly used in the classroom for teacher training degrees (Hernández & Tecpan, 2017; Pedraja, Araneda, Rodríguez, & Rodríguez, 2012), which is consistent with a style called *magisterial* (Biggs & Biggs, 2004), where the lectures are mainly expository and focused on the content (McDermott, 1990), and where the teacher has a dominant role as the absolute owner of knowledge (Bailey & Nagamine, 2012), while the student has a passive role in their own education process (Ortega, 2007). In the specific case of teaching physics, this situation has meant that future teachers do not acquire new strategies to teach in school (Karamustafaoglu, 2009) and, therefore, education is continued that repeats the pedagogical model of reference (Copello & Sanmartí, 2001).

On the other hand, Benegas, Alarcón, and Zavala (2013) argue that teacher training should:

- Favor practical understanding of the principles of physics.
- Favor practical understanding of the basic processes of learning physics.
- Familiarize the participant with (at least one of) the new teaching methodologies for active learning of physics.

There is agreement with the authors that the first condition, although it seems obvious, is not always fully achieved. Studies on the disciplinary knowledge of teachers have shown that, even after receiving university instruction in the subject, they persist with erroneous physics models (McDermott & Shaffer, 2001). Therefore, it should be an important part of the training to provide spaces so that the disciplinary knowledge acquired at each level can be constantly applied, questioned, and evaluated. In this vein, various authors agree on the need to find alternatives so that teachers undergoing training can improve their level of acquired disciplinary knowledge, as there is evidence that this positively influences their effectiveness as teachers (Abell, 2007, Lederman, Gess-Newsome, & Latz, 1994).

Based on the antecedents, this research is centered on the research question "how does the use of active learning strategies affect the disciplinary knowledge of future physics teachers?" In order to answer that, an intervention was designed in a physics teaching course, with the aim that future teachers would appropriate new methodologies centered on the student, which should be used to teach specific content of the subject vis-à-vis their peers.

## Active Learning in Teacher Training

Specifically in the area of physics education, in the last 30 years, the results of various studies have uncovered evidence and knowledge that promote the use of innovative class strategies based on active learning and centered on the student, which improve academic results compared to those obtained from traditional methodologies centered on the teacher (Benegas, 2007; Coletta & Phillips, 2005; De Landazábal, Benegas, Otero, Cabrera, Espejo, Seballos, & Zavala, 2010; Hake, 1998; Jackson, Dukerich, & Hestenes, 2008; Meltzer & Shaffer, 2011; Meltzer & Thornton, 2012; Redish, 2003). These strategies promote lasting learning in students and also encourage the development of other skills that are difficult to attain under the traditional model (Zhu & Geelan, 2013).

This study considers *Active Learning* as a process in which students carry out various activities that promote analysis, synthesis, and evaluation, in accordance with the definition provided by the Center for Research on Learning and Teaching of the University of Michigan[1]. Unlike traditional methodologies, focused on the content, the student is placed at the center of learning and collaborative work is promoted between peers. According to Benegas (2011), some of the differences between content-focused, or traditional, learning and active learning, are:

- When the learning is focused on the content, the main source of knowledge for the student is the guide book and the teacher themselves; however, in active learning, the observation of the real world is validated as the main source of knowledge.
- The beliefs of the students are not explicitly challenged in a class with a traditional approach, while in an active classroom students have to compare their predictions and beliefs with the results of experiments and observations.
- The role of the teacher changes from being an authority under the traditional approach to being a guide in the active learning process.
- In content-centered learning, the student's role is mostly passive, while in active learning the student is encouraged to follow their own learning process, guided by the teacher and in constant collaboration with their peers.
- Student-centered learning emphasizes conceptual understanding and the development of collaborative skills, as well as reasoning and argumentation.

Based on these characteristics, active learning strategies emerge as an alternative for the future teacher to acquire tools that allow them to transform the scientific knowledge acquired into teachable knowledge (Abell, 2007).

In this study, and for the intervention designed, we went more deeply into certain *active strategies* for learning physics at the university level, a brief description of which is shown below:

- Interactive Lecture Demonstrations (Sokoloff & Thornton, 2004). This consists of using a series of worksheets with specific instructions in class to observe the demonstrations. Students predict the results of the demonstrations, discuss them in small groups, observe the results, compare their predictions, and explain the agreement or disagreement between their predictions and what they observe.
- Peer Instruction (Mazur, 1997). This refers to discussions in small groups (two or three students) about conceptual questions that are combined with brief capsules of information. This promotes growing cognitive involvement on the part of the student, in addition to obtaining immediate formative feedback on the evolution of class thinking.
- Context-Rich Problems (Heller & Hollabaugh, 1992; Heller, Keith, & Anderson, 1992). In this strategy, the students work in small groups using a series of steps, similar to those used by experts to solve complex, context-rich problems, where the students appear as the protagonists of the situation so they become involved. These problems must be sufficiently difficult to resolve individually, which enhances collaborative work, but not so complex so that students become discouraged.

1 http://www.crlt.umich.edu/tstrategies/tsal. Last visited on July 22, 2017.

- Inquiry-Based Learning (Anderson, 2007). This involves conducting "guided" research in the laboratory to develop profound comprehension of physical concepts and scientific reasoning skills. The students make observations, develop physical concepts, use and interpret scientific representations, and construct predictive explanatory models.
- Modeling Instruction (Hestenes, 1987). The emphasis of this strategy is the active construction of conceptual and mathematical models that are developed by the students in small groups, which are formed like learning communities.

The methodological characteristics of the study and the details of the intervention carried out are presented below, an instance in which the active learning strategies indicated have been incorporated into the didactic physics course for teacher training.

## Methodology

To address the research question, a methodological intervention was designed and implemented for a didactic course in a university program for initial teacher training, which was aimed at teaching students to use various active learning strategies to teach physics.

A pre-experiment was conducted in a single group with a pre-test-posttest design (Hernández, Fernández, & Baptista, 2006), of the G1 O1 X O2 type, where:
G1: Students on the physics didactics course
O1: Initial level of disciplinary knowledge
X: Intervention
O2: Level of disciplinary knowledge subsequent to the intervention

**Sample (G1)**

Twenty-eight students on a didactic course studying for a degree in Pedagogy in Physics at a Chilean state university took part. The average age of the participants was 21. Some 39% of them were women and 61% men.

**Initial and final level of disciplinary knowledge (O1 and O2)**

As this subject is in the sixth semester of the degree program, students had prior disciplinary knowledge in subjects such as classical mechanics, a course that had been passed by all of the participants. Considering that this content is one of the subjects with the greatest presence in the secondary education curriculum for physics in Chile, it was decided to focus the intervention and use of active learning strategies on teaching the basics of classical mechanics.

To determine the level of disciplinary knowledge of the future teachers at the beginning and end of the intervention, the Force Concept Inventory, or FCI (Hestenes, Wells, & Swackhamer, 1992), was used in its revised edition of 30 items (Hestenes & Halloun, 1995) and translated into Spanish by Macia-Barber, Hernández, and Menéndez (1995).

The questions in the instrument are multiple choice and allow knowledge to be evaluated about the force concept through different dimensions: kinematics, Newtonian principles, types of forces, and the principle of superposition. Using the instrument allows not only how much the student knows to be established, but also what their conceptual models on the subject are. Table 1 shows the details of the contents assessed and the corresponding questions in each case.

Table 1
Conceptual content of the FCI

| Content | Item N° |
|---|---|
| Acceleration is independent of mass | 1, 2 |
| Force of gravity | 3, 13, 29 |
| Newton's 1st Law | 6, 7, 10, 23, 24 |
| Newton's 2nd Law | 8, 9, 18, 21, 22, 26 |
| Newton's 3rd Law | 4, 15, 16, 18, 25, 28 |
| Forces that act in a uniform circular motion | 5 |
| The principle of superposition of forces | 11, 17 |
| Parabolic motion | 12, 14 |
| Kinematics. Difference between speed and acceleration | 19, 20 |
| Forces of friction | 27, 30 |

**Intervention made (X)**

The intervention in the physics didactics course is aimed at providing the future teacher with theoretical and technical tools so that they learn the fundamentals that sustain the processes of teaching and learning of the subject in the classroom during a semester. The implementation was carried out in 2015.

From the start of the course, the lectures were carried out with activities that enhanced collaborative work and were focused on the active role of students. The contents of the course were temporarily distributed as follows:

- Weeks 1-4: Fundamentals of teaching and learning of science and specifically physics.
- Weeks 5-8: Teaching of active learning strategies: modeling, inquiry, peer instruction, interactive lecture demonstrations, solving context-rich problems.
- Weeks 9-11: Class planning and design of teaching material for their implementation.
- Weeks 12-16: Implementation of planned classes in the classroom. The students acquire the role of teacher and/or student of their peers.
- Week 17: Application of post-test and assessment of portfolios prepared with the classwork.

In week 8, the FCI questionnaire was applied as a pre-test, in order to identify which concepts presented the most difficulty for the students. Based on the results obtained (Figure 2), work teams of three or four students were formed, grouping them according to the affinity of the test results, that is, the students who obtained the lowest results in the same subject were added to the same group.

The objective of this distribution was to encourage, starting in week 9, the activity of planning classes and designing teaching resources to be carried out to teach specific content: that in which the entire group had the greatest conceptual difficulty. This decision allowed the students to address the challenge of teaching the content and, therefore, address the study of related phenomena.

However, given the interest that the intervention would allow students to appropriate active learning strategies, it was a requisite that the planned class would not be carried out in an expository or traditional manner. To do this, each group could choose which active learning strategy, of those previously learned, they wanted to use to design their class. The distribution of content and strategies by team is summarized in Table 2. It should be noted that, in certain subjects, there were two teams with different associated strategies, because these subjects obtained lower results in the pre-test for a greater number of students, so they needed to be reinforced.

Table 2
Distribution of disciplinary content and strategies proposed by work group

| Team | Disciplinary content – FCI | Type of active strategy |
|---|---|---|
| 1 | Principle of superposition of forces | Peer instruction |
| 2 | Acceleration independent of mass | Modeling |
| 3 and 4 | Newton's 2nd principle for constant forces | Interactive Lecture Demonstration and Modeling |
| 5 and 6 | Newton's 3rd principle for continuous forces | Interactive Lecture Demonstration and Context-Rich Problems |
| 7 | Forces in uniform circular motion | Inquiry |
| 8 | Air resistance | Inquiry |
| 9 | Difference between speed and acceleration | Context-Rich Problems |
| 10 | Parabolic motion | Peer Instruction |

When implementing the planned physics class with the chosen active learning strategy, the students on the team assumed the role of teacher and the classmates adopted the role of students and peer evaluators. Classes lasted 30 minutes per team, plus 15 minutes for full discussion and later feedback. Thus, during each session of the course two planned classes were implemented.

As students, the future teachers had the opportunity to participate in active physics classes, different from the expository lectures they received during their training. As peer evaluators, they were able to reflect on the disciplinary, pedagogical, and didactic characteristics of each class conducted. Thus, the intervention favors learning about the teaching and learning of physics with active strategies from the three possible positions.

**Technical analysis of data**

In order to analyze the FCI data, we used normalized gain analysis (Hake, 1998), understood as the ratio between the gain obtained on a course (difference between the pre-test applied at the start of the course and the post-test applied at the end of it) and the maximum gain possible, that is, the difference between the maximum possible result (perfect score) and the initial situation (pre-test):

$$g = \frac{post\ test\ \% - pre\ test\ \%}{100 - \%\ pretest}$$

In addition, the Student's t-test for dependent samples was applied to determine whether this difference was statistically significant (Sheskin, 2007).

Throughout the process, ethical standards were taken into consideration, through authorizations signed in informed consent forms designed for the intervention and corresponding collection of data.

## Results

In the statistical analysis, the assumptions of the Student's t-test for dependent samples were verified, which allows comparison before and after a didactic intervention (Sheskin, 2007). The data suggest that the participants increased their level of disciplinary knowledge at the end of the course (Average = 73.2, SD = 16.46), compared with what they showed at the beginning of the course (Average = 55.7, SD = 19.27), so there is a statistically significant result ($p$ <0.001, $t$ = 6.145, $df$ = 27). The size of the effect found is large ($d$ = 0.97) and the power of the test was 99%, which exceeds the reference value of 80% (Connolly, 2007).

In the pre-test, an average performance of 56% was obtained (SD = 19.27) and in the post-test the average performance was 73% (SD = 16.46). Figure 1 shows a graph with the performance of each participant in both tests. The Hake gain was calculated with these data, obtaining a value of $g$ = 0.40, which, according to the classification proposed by the same author, corresponds to an average gain, since it is within the interval equal to or greater than 0.3 and less than 0.7.

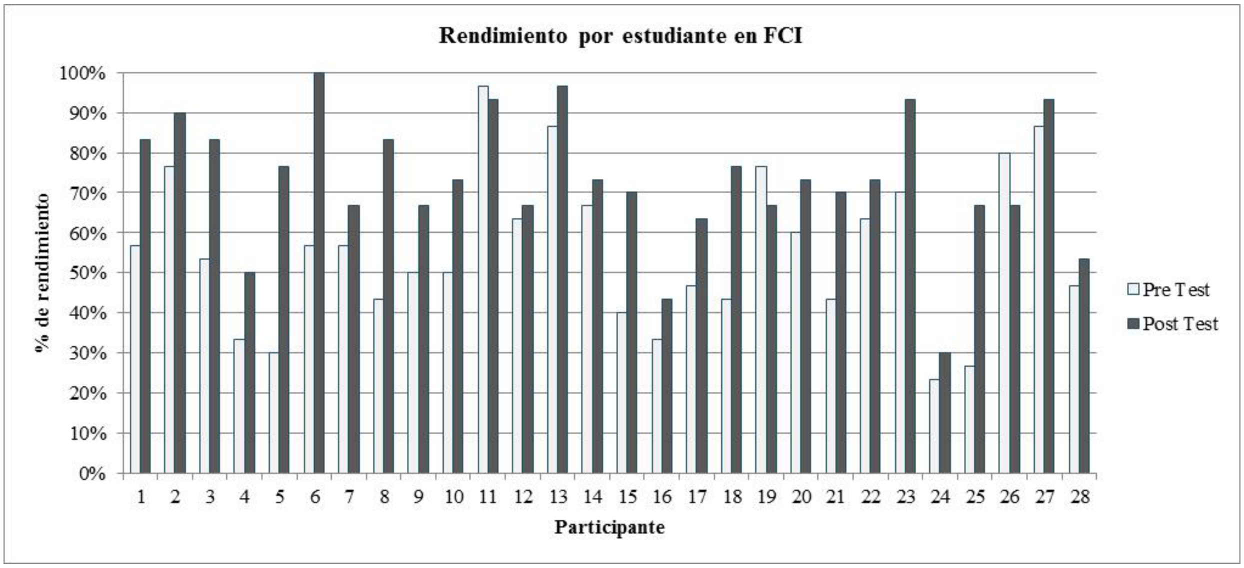


Figure 1. Performance of the 28 participants in the pre-test and posttest.

When performing the analysis of the level of gain by student in the pre-test, it was found that 11% obtained a gain lower than 0.3, considered as low, while the majority, or 68% of the students, achieved an intermediate gain, that is, equal to or greater than 0.3 and lower than 0.7. Thus, only 21% of the participants achieved a level of knowledge considered to be high. In comparison, after the intervention with active strategies carried out, the results in the posttest show that only 4% of the students were in the low performance range, with the number of students with a high performance increasing to 53%. This result shows that the intervention was effective, favoring a large number of students moving from a low to a high level of conceptual understanding.

It should be noted that, in the intervention carried out in the didactic course, the students addressed the issues whose results in the pre-test were lower than 60% of the performance obtained, that is, those subjects that presented the most difficulties for the students and which were reflected in the number of correct answers obtained by item. The graph in Figure 2 shows the results obtained in the pre-test and posttest for each item.

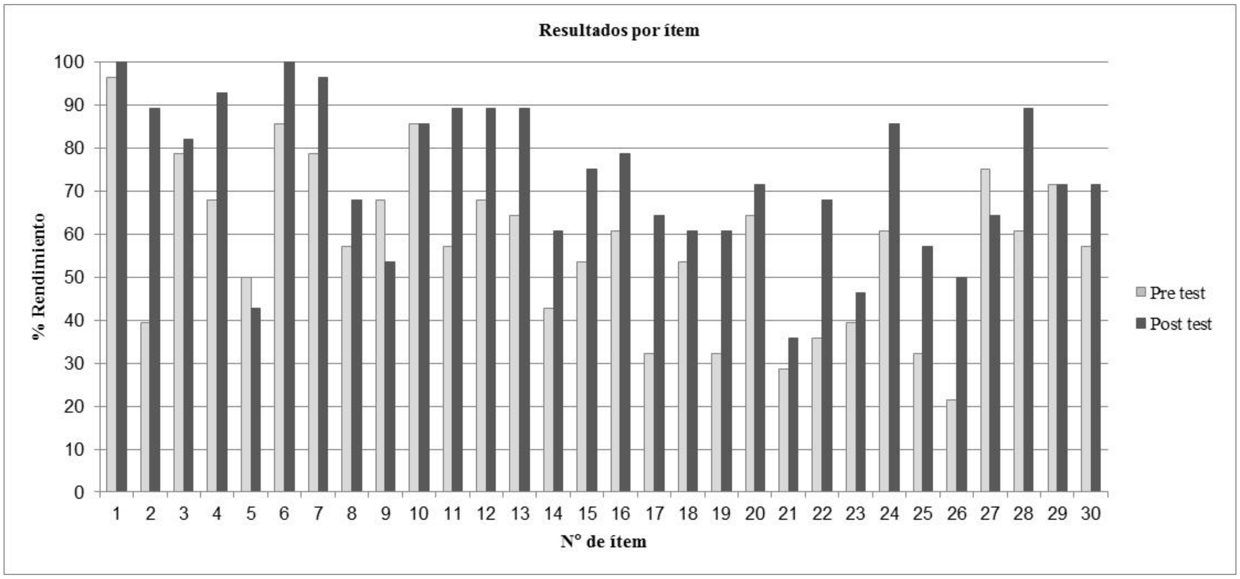


Figure 2. Performance of the students for each item in the pre-test and posttest.

Due to the results obtained in the pre-test, the topics of questions 2, 17, 19, 21, and 26 (shown in Table 2) were a priority to assign among the groups, as the performance of the students did not exceed 40%. In order to have a greater variety of topics, those corresponding to other items where students obtained a performance of lower than 60% were also assigned.

When comparing the performance obtained in the post-test for the set of items whose topics were addressed by the students in the intervention, an increase of up to 50% in the results was observed. Except in the case of question 5, the students increased the number of correct answers in all of the disciplinary contents that were addressed with the intervention. This result also suggests the effectiveness of the intervention conducted. The discrepant case is not addressed in this study, given the significance of the overall impact.

From the perspective of gender, in terms of the level of conceptual knowledge of the content, the results were higher for men. However, according to the graph in Figure 3, women show a greater increase in average gain compared to men, which would indicate greater benefit in the use of the proposed intervention for women. In other words, the intervention conducted narrowed the gap in pre-existing results by gender, in terms of future teachers' level of conceptual knowledge about the disciplinary content addressed.

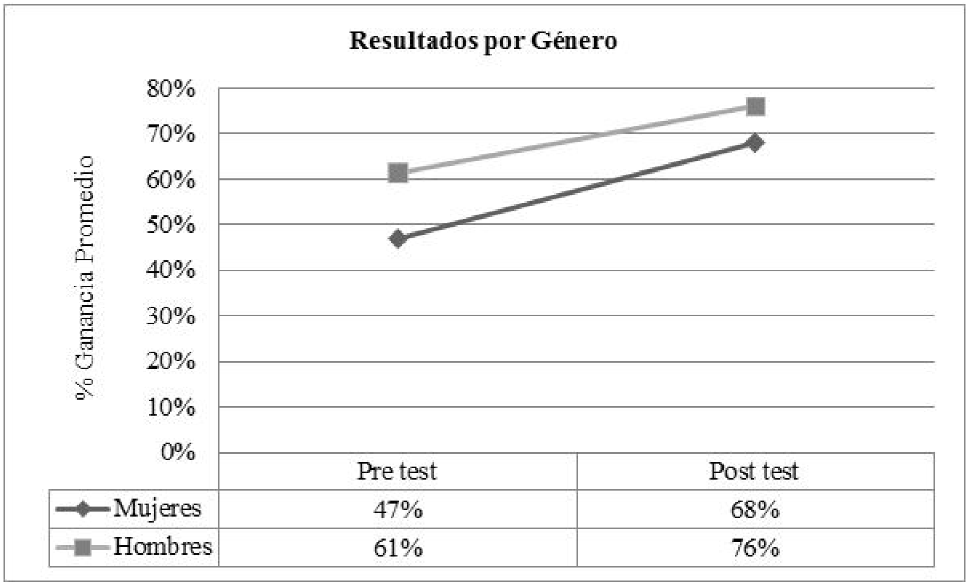


Figure 3. Average gain obtained by men and women in pre-test and posttest.

Various studies have recommended using active learning strategies to increase women's participation in physics and the sciences (Halpern, Aronson, Reimer, Simpkins, Star, & Wentzel, 2007; Rosser, 1995). Nevertheless, the results in this regard are not conclusive, as some contradictory results appear (Madsen, MacKagan, & Sayre, 2013), which call for more research into specifically which factors in these strategies for teaching physics are the ones that effectively influence the gaps between genders.

## Discussion and Conclusion

The results of this study suggest that active learning strategies contribute to improving the level of disciplinary knowledge, since students achieved greater conceptual understanding at the end of the intervention. These findings show that the participants manage to improve the pre-Newtonian models of thought that had not been addressed in their previous training, given that the teaching mainly focused on the content. This result is consistent with those obtained in other studies where active learning methodologies have been used to address disciplinary content, and specifically mechanics (Benegas, 2007, Zavala, Alarcón & Benegas, 2007). However, it should be noted that, unlike the research carried out in physics courses, this study addressed the problem from the perspective of a didactic course where the objective was to learn to teach physics and not learn the disciplinary content. Therefore, the effective gain obtained is related to the use of active learning strategies, but within the framework of a process of construction of didactic transpositions to teach the disciplinary content (Chevallard, 1991).

From the perspective of the reduction in the gender gap, the impact of the intervention was greater in women than in men. The results obtained agree with those of other studies that have suggested that women may benefit more from this type of strategy (Laws, Rosborough, & Poodry, 1999, Schneider, 2001) and that the difference between genders in the academic performance of physics courses is considerably reduced (Madsen et al., 2013). The characteristics of these strategies suggest that their use can influence the gender gap, given that women have more opportunities to express their ideas in group discussions (Lorenzo, Crouch, & Mazur, 2006).

By way of conclusion, and in order to answer the research question posed, the evidence suggests that the use of active strategies in the didactic course, through an intervention such as that designed for this study, significantly and positively influences the level of disciplinary knowledge of future teachers, since they manage to learn and reinforce it while they have opportunity to reflect on how to teach it to their peers.

## Implications and Limitations

According to the work carried out, implications emerge for future studies, firstly considering that the above is an isolated experience in a case study, so it is therefore suggested to incorporate active methodologies based on a more overall view of the training curriculum for teachers, in other contexts, and with the possibility of promoting the improvement of disciplinary knowledge in content other than physics. Similarly, the intervention can be replicated for training programs for teachers in other specialties and subjects.

Additionally, taking into account that the intervention was always carried out between peers on the didactic course, it is interesting for a subsequent stage to follow up on the future teachers in their professional practice at the end of their degree, so that they apply the strategies learned in real school classroom contexts and in an individual manner.

One of the limitations of the study is the sample size and the number of students enrolled in the course, which implies a smaller time commitment for the preparation and execution of each class, that is, the greater the number of students on the course, the greater the number of groups that are formed and the greater the time needed to implement the designed classes. From this point of view, it is difficult to carry out the intervention with a larger sample, unless the course lasts more than a semester, or several parallels of the subject are formed. In addition, when conducting the intervention within the framework of a didactic course that only lasts one semester, it is difficult to address more than one area of disciplinary content as the basis of the students' work, because it is necessary to apply a conceptual test in the pre and post instruction mode for any content in order to demonstrate the impact of the intervention performed. For this reason, it is suggested that the specific didactics as a subject in the teacher training should be more extensive, allowing interventions such as those proposed here. These limitations relate to the management of the teacher training curriculum and, therefore, they are beyond the methodological decisions of the researchers and professors of the subject.

The findings suggest that new studies should go more deeply into understanding the causes of the gender differences identified in the results, as well as differentiating the impact that each separate active learning strategy can have on disciplinary knowledge in teacher training.

Finally, future research could also include the advances seen in a field that has developed a great deal and had a significant impact; the study of conceptions about teaching and learning at university (Biggs, 2001; Entwistle, 2007; Entwistle, Skinner, & Entwistle, 2000).

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