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A CONTRIBUIÇÃO DO ENSINO E APRENDIZAGEM DE FÍSICA BASEADA EM PESQUISA NA FORMAÇÃO INICIAL DE PROFESSORES: DESAFIOS E OPORTUNIDADES

CONTRIBUTION OF INQUIRY-BASED PHYSICS TEACHING AND LEARNING IN INITIAL TEACHER TRAINING: CHALLENGES AND OPPORTUNITIES

CONTRIBUCIÓN DE LA ENSEÑANZA Y EL APRENDIZAJE DE LA FÍSICA BASADA EN LA INDAGACIÓN EN LA FORMACIÓN INICIAL DE DOCENTES: DESAFÍOS Y OPORTUNIDADES

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RESUMO:

Introdução: A Educação Científica Baseada em Investigação (EBSE) é uma estratégia educacional na qual os alunos seguem métodos e práticas semelhantes às realizadas por cientistas para construir novos conhecimentos. Objetivo: **Objetivos:** O objetivo desta pesquisa foi analisar os desafios colocados pelas atividades de investigação na formação inicial de professores de física. **Métodos:** O presente estudo foi de natureza exploratória. A amostra foi composta por 60 alunos de um programa de formação de professores de física. Os dados foram coletados por meio do questionário Matemática e Ciências na Vida, MASCIL. **Resultados e Discussão**: mostraram que as atividades de investigação são um recurso potencial para o ensino de ciências. Além disso, verificou-se que quando as atividades são implementadas de forma sistemática (ou seja, planejadas e desenhadas com propósitos bem definidos), tanto alunos quanto professores são mais ativos e comprometidos em sua participação, e os alunos podem melhorar seu desempenho. Da mesma forma, os resultados mostraram que os professores têm visões positivas com base nos benefícios para os alunos e a aprendizagem de ciências e percebem barreiras sistêmicas e pessoais significativas para a implementação do IBSE mesmo após décadas de esforços políticos para melhorar o ensino de ciências. Os professores expressaram frustração com a falta de tempo, recursos didáticos, gestão da sala de aula e as demandas de entrega, avaliação e responsabilidade do currículo. Além disso, há uma ênfase nas atividades práticas e na motivação dos alunos, mas não nos aspectos cognitivos e epistêmicos que mostram pontos de vista que não estão bem alinhados com a compreensão atual do tipo de pesquisa que melhor suporta a aprendizagem. **Conclusões:** As implicações para a pesquisa e a prática sugerem que ainda há necessidade de ampliar o conhecimento sobre como ajudar os professores a aproveitar ao máximo essa estratégia.

Palavras-chave: *Formação de professores de física, aprendizagem por investigação, avaliação de práticas científicas, aprendizagem ativa*.

ABSTRACT

Background: Inquiry-Based Science Education (IBSE) is an educational strategy in which students follow methods and practices similar to those carried out by scientists to build new knowledge. **Aims:** The objective of this research has been to analyze the challenges posed by inquiry activities in the initial training of physics teachers. **Methods**: The present study was exploratory in nature. The sample was made up of 60 students from a physics teacher training program. The data were collected through the Mathematics and Science in Life questionnaire, MASCIL. **Results and Discussion:** showed that inquiry activities are a potential resource for science education. In addition, it was found that when the activities are implemented systematically (that is, planned and designed with well-defined purposes), both students and teachers are more active and committed in their participation, and students can improve their performance. Likewise, the results showed that teachers have positive views based on the benefits for students and science learning and perceive significant systemic and personal barriers to implementing IBSE even after decades of political efforts to improve science education. Teachers expressed frustration at the lack of time, teaching resources, classroom management, and the demands of delivery, evaluation, and accountability of the curriculum. Furthermore, there is an emphasis on practical activities and student motivation but not on cognitive and epistemic aspects showing points of view that are not well aligned with the current understanding of the type of research that best supports learning. **Conclusions:** The implications for research and practice suggest that there is still a need to expand knowledge on how to help teachers make the most of this strategy.

Keywords: *Physics teacher training, inquiry-based learning, evaluation of scientific practices, active learning*.

RESUMEN

Introducion: La Educación en Ciencias Basada en la Indagación (IBSE) es una estrategia educativa en la que los estudiantes siguen métodos y prácticas similares a las que llevan a cabo los científicos para construir nuevos conocimientos. **Objetivo:** El objetivo de esta investigación ha sido analizar los retos que plantean las actividades de indagación en la formación inicial de profesores de física. **Métodología:** El presente estudio fue de naturaleza exploratoria. La muestra estuvo conformada por 60 estudiantes de un programa de formación de profesores de física. Los datos fueron recolectados a través del cuestionario Matemáticas y Ciencias en la Vida, MASCIL. **Resultados y Discusión:** mostró que las actividades de indagación son un recurso potencial para la enseñanza de las ciencias. Además, se encontró que cuando las actividades se implementan de manera sistemática (es decir, planificadas y diseñadas con propósitos bien definidos), tanto los estudiantes como los docentes son más activos y comprometidos en su participación, y los estudiantes pueden mejorar su desempeño. Asimismo, los resultados mostraron que los docentes tienen opiniones positivas basadas en los beneficios para los estudiantes y el aprendizaje de las ciencias y perciben importantes barreras sistémicas y personales para implementar IBSE incluso después de décadas de esfuerzos políticos para mejorar la educación científica. Los docentes expresaron su frustración por la falta de tiempo, recursos didácticos, manejo del salón de clases y las exigencias de entrega, evaluación y rendición de cuentas del currículo. Además, hay un énfasis en las actividades prácticas y la motivación de los estudiantes, pero no en los aspectos cognitivos y epistémicos que muestran puntos de vista que no están bien alineados con la comprensión actual del tipo de investigación que mejor apoya el aprendizaje. **Conclusiones:** Las implicaciones para la investigación y la práctica sugieren que aún existe la necesidad de ampliar el conocimiento sobre cómo ayudar a los docentes a aprovechar al máximo esta estrategia.

Palabras claves: *Formación de profesores de física, aprendizaje basado en la indagación, evaluación de prácticas científicas, aprendizaje activo*.

1. INTRODUCTION:

The self-assessment processes and the review of the scientific literature have revealed that it is necessary to incorporate different strategies for teacher training. Dynamic methodologies that involve students and teachers in inquiry tasks in real contexts are scarce. When facing the new challenges of humanity, it is essential that physics education also make changes aiming to achieve better performance levels among future teachers in the early pre-service stages.

Inquiry-Based Science Education (IBSE) is an educational strategy where students follow methods and practices similar to those carried out by professional scientists to build knowledge (Keselman, 2003). IBSE is a causal process that allows students to formulate hypotheses and test them, thus contrasting them through experimental activities and/or observations (Pedaste *et al*., 2012). It emphasizes the participation and responsibility of students to discover new knowledge for them (de Jong and van Joolingen, 1998). With IBSE, students often carry out self-directed learning processes, partly inductive and partly deductive, while experimenting with investigating the relationships between dependent and independent variables. For several decades, science educators insisted on modifying, or at least renewing science teaching methodologies; likewise, IBSE has been considered to develop scientific thinking (NRC, 2000).

Several quantitative studies have evinced the effectiveness of IBSE as an important methodological approach in science education. For instance, Alfieri *et al*. (2011) conducted a meta-analysis comparing inquiry with other forms of teaching, such as direct instruction or unaided discovery. They found that inquiry-based teaching resulted in better learning results for students (mean effect size of d = 0.30). Similarly, a recent meta-analysis by Furtak *et al*. (2012) used a wide range of terms to describe inquiry-based learning (e.g., subject learning, constructivist teaching). They found an overall mean effect size of 0.50 in favor of the inquiry approach compared with traditional teaching methodologies. Finally, recent studies have shown that inquiry-based learning, if properly designed, may lead to better results than other forms of direct teaching (Furtak *et al*., 2012). Even educational policy management institutions worldwide have considered IBSE an essential component in building a scientifically literate community.

Inquiry-based science education research

The inquiry has played a key role in school science programs for less than a century (Bybee and DeBoer, 1993). However, before 1900, most teachers viewed science primarily as a body of knowledge that students had to learn through direct teaching and rote learning. A critique of this perspective came about in 1909, when John Dewey, in an addressing to the American Association for the Advancement of Science, argued that science teaching emphasized the accumulation of information and little on the scientific activity as a form of thinking and mental attitude. To learn, science is more than a knowledge set, Dewey asserted, and a process or method is inherent to science learning (NRC, 2000; Crawford, 2014).

For Seidel and Shavelson (2007), there is a variety of terms in the literature for IBSE: research-based teaching and learning (NRC, 2000), authentic research (Chinn and Malhotra, 2002), model-based research (Windschitl *et al*., 2008), modeling and argumentation (McNeill *et al*., 2006), project-based science (Singer *et al*., 2000), practical science (Pine *et al*., 2006), and constructivist science (Hardy *et al*., 2006). For Klahr and Li (2005), this variety of names has made it difficult to advance research in science education due to the non-unified operational terms of what constitutes and what does not constitute reform.

A meta-analysis was conducted to illuminate this variety of terms, comparing and contrasting the different effects found in IBSE. Thirty-seven studies that met the inclusion criteria resulted in a mean effect size of 0.50, which indicates a positive effect of IBSE on student science learning. In this sense the type of study, by different disaggregating domains of a two-dimensional research model, has helped identify particular characteristics of these practices that seem to have stronger links to better science learning results in students (Furtak *et al*., 2012). Furthermore, another large effect size was found for students who contrasted procedural, epistemic, and social dimensions. The effect size of this subset of studies on student learning supports the science education community's view that inquiry-based teaching has a large positive effect on student learning.

Additionally, research has consistently shown that IBSE can be more effective than lecture-based approaches for science education, as long as students receive appropriate support (Lazonder and Harmsen, 2016). However, the question of what type of Teacher orientation is most suitable and for whom remains fairly unattended even. In a recent investigation on this aspect, the results of 72 research reports were synthesized to compare the effectiveness of different types of guidance in different age groups. Findings included general facilitating effects of guidance on learning activities, performance success, and learning outcomes. The type of orientation moderated the effects on performance success but not on the other two outcome measures. A considerable variation was found in the effects of counseling on learning activities. However, the relatively low number of studies does not provide definitive conclusions about possible age-related differences (Lazonder and Harmsen, 2016). However, this may provide a preliminary idea of the scope of IBSE concerning counseling. On the other hand, De Jong *et al*. (2013), based on a synthesis of well-controlled comparative studies, concluded that inquiries made with physical materials are as effective as technology-enhanced research for the acquisition of conceptual knowledge using either computerized simulations or online labs.

These findings were partially confirmed (D'Angelo *et al*., 2014). Specifically, simulations presented a performance advantage over reduction in science without simulation (d = 0.62) but did not affect students' learning activities (d = 0.26). However, these results should be treated rather cautiously because the non-simulation condition implied "some other type of instructional treatment" (p. 14), which does not rule out the possibility that the effect of using simulations was confused with the teaching method.

Similarly, Alfieri *et al*. (2011) found that inquiry-based methods with minimal or no assistance are less effective than explicit teaching (d = 0.38). Students who are properly guided during inquiry learn more (d = 0.30) than those taught the same content through direct instruction methods.

This has also been corroborated by Furtak *et al*. (2012), who found that students who participated in a consultation with minimal guidance from their teacher tended to learn more than students exposed to "traditional teaching" (d = 0.25). After comparing teacher-led inquiry against traditional instruction, the former obtained a considerably higher overall mean effect size than the latter (d = 0.65). The magnitude of this effect could not be replicated in the meta-analysis by Wickens *et al*. (2012), who found a small but significant general benefit (g = 0.15) related to learning guided by Inquiry Activities.

In conclusion, state-of-the-art provides compelling evidence that inquiry-based methods can be more effective than expository teaching methods. Its effectiveness has been mainly demonstrated in the learning outcomes assessed after a task by post-tests in a particular area. However, integrated assessment of the actions that students take during the consultation (i.e., learning activities) and the quality of the products they create during the consultation (i.e., performance success) has received significantly less attention. The second conclusion that can be drawn is that the effectiveness of inquiry learning depends directly on the availability of adequate guidance. Appropriate types of counseling cannot be determined based on existing reviews and meta-analyses. However, it is an important guide to understanding what works and what does not. This seems to occur, at least in part, because counseling is often classified as *ad hoc*. The use of one *a priori* classification based on a robust theoretical framework could be fruitful and might facilitate the interpretation of the findings. In short, although some attention has been given to the possible moderating effects concerning students' age, the relative effectiveness of the types of orientation for the different age groups and areas has not yet been evaluated (Lazonder and Harmsen, 2016). Based on this observation, we found clear opportunities for research and innovation.

On the other hand, a study on the visualization of collaborative inquiry-based learning (CIBL) processes revealed the need for scenarios that focus on research, technological, and collaborative skills at the beginning of the learning process (Lämsä *et al*., 2018). This revelation is important as to how including Information and Communication Technologies (ICT) to mediate the IBSE may spawn methodological innovations.

Moreover, in a recent study on how individual curiosity differences in children aged 7 to 9 were related to the inquiry-learning process and its outcomes in structurally different environments, it was found that children's curiosity was positively related to the acquisition of knowledge but not to the quality of the exploration. For children with fewer scientific skills, the structure of the environment positively affected their exploration quality but not their knowledge acquisition. There was no significant interaction between curiosity and the structure of the environment. These results support two different inquiry-based learning processes: the design of experiments and reflection on the experiments. Children's curiosity seems to be more linked to the latter (Van Schijndel *et al*., 2018).

Of course, we must keep in mind that this methodology is also criticized. Osborne (2019, p. 1280) discusses the conventional belief that science education should be practical and phenomena-oriented. He argues, citing Frank and Penuel (2018) and Driver *et al*. (2000), that science should be oriented to explain phenomena while considering them as "the 'maidens' of rational activity of generating arguments in support of knowledge claims."

In line with the previous perspectives, the theoretical framework assumed in this research is based on the works of the NRC (2000) and Pedaste *et al*. (2015). IBSE aspires to engage students in an authentic process of scientific discovery. In this sense, the educational literature describes a variety of phases and cycles of research. For instance, the 5E learning cycle model (Bybee *et al*., 2006) lists five phases of inquiry: Engagement, Exploration, Explanation, Elaboration, and Evaluation. A research cycle proposed by White and Frederiksen (1998) also proposes five research phases, labeled Ask, Predict, Experiment, Model, and Apply. An apparent distinction between these examples is that the two initial phases of the 5E cycle (Engagement and Exploration) suggest starting with an inductive (empirical/data-driven) approach.

In comparison, the first two phases of White and Frederiksen's research cycle (Ask and Predict) suggest a deductive approach (based on theory/hypothesis). However, inductive and deductive approaches can coexist in an inquiry cycle. Klahr and Dunbar (1988) characterized the process of scientific reasoning as a dual search in two spaces, which they call *the experiment space* and *the hypothesis space*. The research phases are influenced by the approach chosen, either deductive or inductive.

How a cycle is presented generally suggests an orderly sequence of phases. However, researchers often avoid adding a disclaimer that inquiry-based learning is neither a prescribed nor uniform linear process. Connections between phases may vary depending on the context. For example, in a cycle of inquiry proposed by Justice *et al*. (2002), a single research phase (self-reflection/self-assessment) is directly connected to the other phases. Based on the general vision of the proposed research phases and sub-phases and their definitions, a research-based learning framework was developed, which is the one assumed in this research (Pedaste *et al*., 2015). This can be observed in Figure 1.

According to a study by Pedaste *et al*. (2015), three possible routes can be identified: (a) Orientation - Questioning - Exploration - Questioning - Exploration - Data interpretation - Conclusion; (b) Orientation - Hypothesis generation - Experimentation - Data interpretation - Hypothesis generation - Experimentation - Data interpretation - data interpretation to the conclusion; communication and reflection can be added to each phase); (c) Orientation - Questioning - Hypothesis generation - Experimentation - Data interpretation - (Questioning) Hypothesis generation - Experimentation - Data interpretation – Conclusion.

The framework presented in Figure 1 broadly reflects a contemporary view of inquiry-based science Learning (IBSL). It is derived from a systematic review of the frameworks found in the educational research literature and is an attempt to cover many different implementations of IBSL. While earlier IBSE frameworks may have neglected metacognitive processes, Figure 1 includes these Frameworks in the discussion phase and linked with the four phases of general transformative inquiry. The possibility that IBSE may primarily follow an inductive or deductive reasoning approach, as Klahr and Dunbar (1988) explain, is captured in Figure 1 utilizing various sub-phases within the Conceptualization and Investigation phases. However, the framework is not limited to either approach. The pathways connecting the phases allow for iterations and cyclical movements, thus increasing the range of possible implementations of the inquiry process. This approach assembles different IBSE elements in different ways to carry out various implementations of this methodological cycle (Pedaste *et al*., 2015).

The value of this synthesized framework lies in the possibility that it can constitute the basis of a general framework for IBSL environments, thus providing teachers and students with structured and contextual consultation activities.

Therefore, several general questions arise in this project:

- What phases describe IBSE and are necessary to implement in order to improve the initial education of physics teachers?
- How can the characteristics of the IBSE be integrated into coherent learning experiences to help physics teaching students to achieve high performance during their training process?
- What is the effectiveness of inquiry-based teaching in learning physics when compared to traditional methodologies?

The present research aimed to achieve the following:

- Encourage and model scientific inquiry skills, scientific curiosity, methodological openness for creative data treatment, and scientific skepticism.
- Identify and analyze the core characteristics of the cycles of inquiry relating to effectiveness in learning physics at the university level.
- Analyze some specific challenges posed by an open inquiry task in developing scientific practices in physics teaching.
- Describe and analyze some teaching practices of teachers in a university Physics Education program when implementing inquiry-based activities in their classes.
- Learn what drives a teacher to promote inquiry learning, or not, in science and math teacher training classes in general.

2. MATERIALS AND METHODS:

The research methodology that we will use combines experimental and case study techniques (Mixed methods design). To achieve the main objective of this research, we have resorted to an experimental paradigm due to the widely accepted theories and models proposed (Creswell, 2012). More specifically, a mixed-methods experimental design (Creswell and Creswell, 2018). This design involves the researcher in quantitative and qualitative data collection and analysis and integration of information within an experiment or intervention trial. Furthermore, it requires the investigator to understand the experiments and be able to rigorously design them.

The specific objective has required analyzing particular cases whose representativeness covers the casuistry found among university students. Therefore, a mixed case study design has been chosen (Creswell and

Creswell, 2018). According to Yin (2018), a case is studied when the unit of analysis is of very special interest, as is the situation of this research. Moreover, the mixed case study design involves using one or more core designs (convergent) within the framework of a single case study design. One of the challenges is understanding case study research (Yin, 2018) and effectively intersecting case study design with mixed methods. Also, according to Yin (2018), case study research is preferable compared to the other methods when (1) the research questions are “how” or “why,” (2) there is little or no control over behavioral events, and (3) the focus of the study is contemporary. Cases can be single or multiple cases, and the case study may be either limited to quantitative evidence or be part of a mixed-methods study.

2.1. Participants

The participants were physics majors from the Faculty of Education of the University of Antioquia (Medellin, Colombia). Students from initial, intermediate, and final semesters were included among the participants to obtain representativeness. In this way, representativeness may be achieved thanks to a well-sized distribution of participants, which permits, in turn, to systematize, compare, contrast, and finally determine meaningful expressions of IBST and IBSL in cases from quantitative as well as qualitative perspectives. In sum, UdeA´s Degree in Physics will be the context addressed, and data has been drawn from third, fifth, and 10th-semester students.

2.2.Instruments

Quantitative data was collected through the Mathematics and Science in Life questionnaire, MASCIL (Maaß *et al*., 2015; Maaß and Engeln, 2016). This Likert-type questionnaire consists of 77 items. The items are distributed in 6 different dimensions or subscales with Cronbach's alpha ranging from 0.89 to 0.68. Information on the validity and consistency of the instrument can be found in the work of Maaß and Engeln (2016).

The instrument was administered to 60 students. Data were collected by extracting information from the subscales related to the orientation and use of IBSL and the barriers and obstacles to implementation in daily teaching. A series of four exploratory interviews were conducted to obtain a richer picture of the students’ view of IBSL. The research determined the number of semi-structured interviews needed to gather sufficient evidence to address the research questions. The research team agreed on a common set of initial open-ended questions to guide the interviews and focus group discussions. However, new topics emerged, and the interviewers introduced additional questions as necessary to better understand the key topics. The interviews were between 45 and 90 minutes. The duration depended on the time needed to cover the previously prepared questions and clearly understand teachers’ responses.

The research ethics committee endorsed this research in social sciences, humanities, and arts: CEI-CSHA (see Annex 1). Likewise, informed consent was obtained from the participants (see Annex 2).

2.3. Procedure

The MASCIL questionnaire was initially administered among students and teachers (Maaß *et al*., 2016) using an online platform. Then, individual interviews were conducted to collect information about students’ learnings based on the different experimental activities. Group interviews and discussions were recorded in videos. Additionally, these interviews were allocated in an artificial intelligence system so that the information provided by each participant was immediately registered on a big data platform due to the high volume of content generated by participants’ speeches.

2.3.1 Data analysis

Individual interviews were transcribed and analyzed by at least two independent researchers using qualitative analysis software (ATLAS.ti) and Microsoft word processing software. An inductive approach was used to identify common patterns, codes, and themes and ultimately agree on particular categories and subcategories. The quantitative data obtained were analyzed with SPSS v.24, JASP, and R using a two-factor ANOVA to test the differences in IBSL orientation among the participants and determine the differences between the methodological conditions considered (i.e., traditional teaching versus IBSE).

3. RESULTS AND DISCUSSION:

3.1. Results

3.1.1. Descriptive analysis of the inquiry activities carried out in the initial training of physics teachers

To determine the differences between men and women related to the implementation and perception of inquiry activities in physics classes, an absolute and percentage distribution of the inquiry dimensions was carried out according to the sex of the Bachelor of Science in Physics students. Physical. The dimensions analyzed were: Enjoyment, Inquiry Value, Self-Concept, Epistemic Interest, Interaction, Practical Activities, and Investigation. Epistemic knowledge refers to the essential defining characteristics for knowledge construction in science (Duschl, 2007). Epistemic knowledge includes understanding the role of questions, observations, theories, hypotheses, models, and arguments in science, recognizing the variety of forms of scientific inquiry, and the role that peer review plays in establishing knowledge that can be trusted (OECD, 2015).

These dimensions emerged from the Applied instrument itself. Cramér's V is a test of the magnitude of the association; that is, the size of the effect. Their values range between 0 (no relationship) and 1 (perfect relationship). It can be seen that the magnitude of the relationship between the variables shows a large effect size. The analysis that allows us to perform Cramer's V is important, as it is an indicator of the possible relationships between variables, independent of the p-value.

The results obtained from the analysis by gender and dimensions showed that there were no statistically significant differences for each of the divisions analyzed (See Table 1). However, when Cramér's V (np) was applied, we found that in the case of the Practical Activities dimension, women consider that they are carried out in most classes about men (M=11 (39.3%) and M=12 (23.5%), respectively with p=0.128, *np*=0.268). (See Table 1).

Likewise, it was found that women enjoyed inquiry activities more (M=19 (67.9%) and N=30 (59.8%), respectively, with a value of p=0.701, np=0.128). These results were also consistent with those of the Value of Inquiry, where women are more in agreement with this dimension than men (M=20 (71.4%) and np=30 (58.8%), with a value p= 0.207 and np = 203. Although the p-value is not significant, the effect size shows a significant difference in the appreciation that women have compared to men with the value that Inquiry Activities give. Finally, verify with the Epistemic Interest, related to the body of knowledge that conditions the way of understanding and interpreting the inquiry processes in the physics class. In this case, of the investigation processes with the inquiry activities, no statistically significant differences between men and women according to the results obtained, p=0.897, np=0.089.

Finally, the inquiry activities related to the Research showed differences between men and women; in particular, men consider that they are performed in some classes to a greater extent (M= 9 (32.1%) and N=25 (49.0%) (See Table 1).

3.1.2. Multivariate multiple correspondence analysis for inquiry activities in physics classes

Multiple Correspondence Analysis (MCA) was chosen to analyze the inquiry processes in physics classes. According to Fernández (20011), the MCA is a descriptive or exploratory type of analysis in which it is intended to summarize a large amount of data in a reduced number of dimensions with the least possible loss of information. In this line, the goal of MCA analysis is like that of factorial methods, except that in the case of correspondence analysis, the method is applied to categorical or ordinal variables. In general, the MCA is oriented to cases in which one variable represents items or individuals, and the rest are qualitative or ordinal variables representing qualities. Correspondence Analysis has two basic objectives: 1) Association between categories of columns or rows: Measure the association of only one row or column to see, for example, if the modalities of a variable can be combined. 2) Association between categories of rows and columns: Study if there is a relationship between categories of rows and columns. In this study, the second option was chosen as it better accommodated the characteristics of the questionnaire used in the research process.

In correspondence with this vision and according to Greenacre, M., and Blasius (2006, p. 197, 198), in the social sciences, the main application of multiple correspondence analysis (MCA) is to visualize the interrelationships between the categories of response to a set of questions in a survey questionnaire, where answers are given according to the established scale. Often there are also many non-responses, and this non-response is a potential category that should also be considered. Once the relationships between the different questions have been established, the method also allows explanatory demographic variables such as age, education, and gender to be displayed to enrich the interpretation.

The analysis allows focusing on a particular subset of categories of the answers given by the subjects. Additionally, it might be of interest to perform the analysis exclusively on the missing responses to understand how they correlate between items and how item non-response correlates with demographic variables. To determine if there are particular questions to which the subjects give insecure answers, an analysis of the category neither agree nor disagree could be carried out. In addition, it would allow determining how the pattern of these responses relates to demographic characteristics.

MCA is generally defined in two nearly equivalent ways: either as (a) simple correspondence analysis (CA) of individual response data in the format of an indicator matrix, where all response categories form the columns of the indicator matrix, or (b) the MCA of all the cross-tabulations concatenated in the so-called Burt matrix, a symmetric matrix that has the response categories as rows and columns. Unfortunately, ACM maps are often overcrowded with dots, making them difficult to print and difficult to interpret.

There are strategies to remedy this situation, such as not plotting points that contribute weakly to the main axes of the map, but this would be undesirable when we are interested in each category in all the questions. Furthermore, it is commonly found that the main dimensions of ACM tell an obvious and unsurprising story about the available data, while the most interesting patterns are hidden in higher dimensions. Exploring more dimensions is not easy because all category points appear and contribute to each dimension, to a greater or lesser extent. The basic problem is that the ACM map tries to show many different types of relationships simultaneously, and these relationships are not isolated in particular dimensions. While the technique does its best to visualize all response categories, the maps may not easily lead to visualizing those relationships of particular interest to the researcher.

Specifically, the multiple correspondence analysis was performed with the Jamovi software for this research. Jamovi is an advanced spreadsheet that enables complex statistical calculations to be performed easily and efficiently, using R as the underlying infrastructure and taking full advantage of it.

This analysis must complement the statistical measures that the analysis throws up. The interpretation can be used based on three elements: the first one is the proximity between the variables. The closeness between the categories will indicate or indicate a high association between these variables. The second element to consider is that the further away from the origin of the variables, the greater the strength of association between that variables.

Therefore, this Figure 1 will not only allow us to see if two categories are associated but also the strength of the association between them. Therefore, the third element that we can consider in the interpretation of the Figure is that categories opposed by the origin will show a negative association.

In the present study carried out in a Physics Degree from a public university in Medellin, Colombia, the following categories were evaluated: the type of Degree, Gender, the Course of Interest or selected by the participants, and the dimensions included in inquiry activities.

So, we wanted to investigate if there was any association between the different variables considered and the processes of implementation of the inquiry in physics classes for teacher training.

After having the visualization map with the multiple correspondence analysis, we select four groups of interest to be analyzed according to the previously established restrictions related to the proximity of the different categories to each other.

In Figure 2, it can be seen that the greater the tendency to orange, the greater the contribution of the association between the variables or categories considered. Or in other words, the further they are from the origin, the greater the strength of association. Another criterion is that categories far from the origin and far from other categories are categories that are not associated with anything. Opposite categories by origin are negative, and they do not present an association.

The results obtained can be seen in Figure 2. Concerning the proximity of the categories, there is no agreed criterion on what it means to be close; However, for practical purposes, it has been considered that proximity is related to the angle formed with the axes.

In this order of ideas, it can be said that for group 1, which is in the upper left part, there is an association between the value of inquiry and the course of thermodynamics; This means that students, and especially women, place a high value on inquiry in this selected course. Likewise, it can be evidenced in this selected group that the women surveyed have a high Self-concept concerning the inquiry processes in physics classes. A relevant element in this group is that, in the case of women, they enjoy the activity of inquiry, particularly the thermodynamics course. In this order of ideas, the results also showed a significant association between sex, particularly female, and the fluid mechanic's course.

The results also showed an important relationship between Enjoyment and the course of electromagnetism. In other words, according to these preliminary results, the surveyed students enjoy the inquiry activities carried out in class, particularly when designing laboratory activities. In addition to this, it was found that there is an essential interaction between the development of activities and the inquiry processes in the said course. This aspect is very interesting because the elements or dimensions of an epistemic type; in deciding related to the nature of scientific knowledge also showed an association with the course of electromagnetism. The Newtonian Mechanics course and an important association with the processes or research activities were shown.

For the third group selected in this multiple correspondence analysis, it was possible to show that the students who selected the wave physics course had a low self-concept of said course; This shows that they did not give value to the inquiry processes carried out in these classes. Likewise, no association was found between this wave physics course and the inquiry activities.

In the case of the fourth group located in the upper right part of the Figure, some worrying results were found. For example, it is striking that no significant association was found between the Quantum Mechanics course and the activities and processes of inquiry. This, at least in this exploratory study, means that few or no inquiry activities are carried out, or they may be carried out under other names and with different categories. We reiterate that these results must be replicated because we must not lose sight of the fact that this is an exploratory study.

3.2. Discussions

In this section, we reflect on the results presented above and discuss them in the light of the IBL promulgations, views, barriers, and limitations and in the light of the research goals in science education.

3.2.1. Promulgations of IBSL: Traditional Methods VS IBSE Methods

"*Scientific inquiry alludes to how scientists study natural phenomena by proposing explanations based on evidence from their work. The inquiry also refers to student activities in which they develop knowledge and understanding of scientific ideas and an understanding of how scientists study the natural world*" (NRC, 1996, p. 23).

As noted in the National Standards for Science Education (NRC, 1996), students using inquiry to learn science participate in many activities and thinking processes as scientists who seek to expand human knowledge of the natural world. However, the activities and thinking processes used by scientists are not always familiar to the educator seeking to introduce research into the classroom. Describing inquiry in both science and classrooms seeks to explore the many facets of inquiry in science education. Through examples and discussions, it shows how students and teachers can use inquiry to learn to do science, learn about the nature of science, and learn the content of science (NRC, 2000).

One of the best ways to understand school science as research is to visit a classroom where scientific inquiry is practiced (NRC, 2000). This outlook allowed us to introduce a methodology in the learning processes of pre-service teachers based on scientific evidence. This way, we can solve a direct problem of the degree related to the existence of studies and/or projects that promote the modernization, updating, and relevance of the curriculum according to the social, labor, and training needs in the region of influence. However, modernization of the curriculum becomes insufficient when teacher professional development programs are not focused on the needs of teachers and the use of teaching methods using IBL. This is one of the reasons why implementation in the classroom is difficult.

3.2.2. Teachers' and Students' Views of IBSL

The training problem is reflected in on teachers' responses. They show a vision of IBSL enactment as a motivating and collaborative learning process in which students engage in open tasks guided by teachers. It is noteworthy that the teachers offered positive views on IBSL, as they tend towards the affective and procedural aspects instead of articulating positive cognitive or explanatory aspects. They recognize that hands-on activities and manipulation enhance students' motivation, engagement, and understanding. In this study, there is tension between teachers' positive views about inquiry while expressing reluctance about conducting the same. This may be partly due to a prevailing perception that inquiry is "hands-on" and activity-rich classroom inquiry rather than the more sophisticated model described above. Lederman *et al*. (2013) articulated other problems with such perceptions. The author stated, "It is important to emphasize that we must no longer assume that students will come to understand NOS or scientific inquiry as a by-product of 'doing' science-based or research activities, nor should it be assumed that if teachers understand NOS and scientific inquiry, they will automatically teach in a manner 'consistent' with such knowledge. NOS and scientific research should be viewed as 'cognitive' rather than 'affective' instructional outcomes" (p. 144).

This further supports an argument for shifting from emphasizing behavioral outcomes or knowing more about "what scientists do" concerning cognitive and epistemic issues. This means creating a challenge that cognitively engages students within a practical context, focusing on student problem solving, reflection on thinking, and metacognition. In fact, it is argued that enhancing questioning in inquiry classrooms is essential to guide and reinforce students' thinking (Kawalkar and Vijapurkar, 2013).

3.2.3. Barriers and Limitations of IBSL

According to the proposal idea, one question arises: How can the development of teachers' practice be supported for the effective use of IBSL? Identifying limitations is the first step in searching for more effective ways to support teachers in taking advantage of this methodology, from both an individual perspective (teacher professional development and teacher collaboration) and a systemic one (curricular standards, school organization, and evaluation). However, while the evidence reviewed here suggests the need to develop thinking about the type of inquiry to be promoted, it is clear that most teachers believe in the value and importance of developing the use of IBSL approaches. So, why is IBSL used so relatively little, and what could be done about it? Here, data show that one related issue concerns the perceived lack of emphasis on IBSL in initial teacher preparation and in-service professional development moments. The issue of demands to teach in this way points to the importance of exploring this. Crawford (2000) has pointed out that working in this way suggests many ever-changing teacher roles that demand more active and complex participation beyond the commonly used metaphor: the teacher as facilitator. If we want to avoid the failures of our past related to giving teachers a teacher-proof curriculum, we must focus our attention on how to best help teachers embrace the essence of inquiry (p. 935).

This suggests that much clearer attention should be paid to the development of pedagogical practice. Without this commitment to professional development, it is difficult to see how the types of models suggested by the NRC (2012), and advocated by the European Commission (2015), would be put into practice.

Our data also suggest that our teachers see collaboration as an important factor in supporting practice development, which should be included in teacher development processes. The data presented here highlight systemic problems. Many teachers reported difficulties getting appropriate activities, finding time, and managing classrooms to implement IBSL. They expressed concerns about the time constraints of the curriculum, the learning objectives, and the evaluation system. This special concern emphasized research by policymakers, teacher educators, and researchers. How do teachers juggle the competing demands to use a more inquisitive approach and cover the content of the curriculum in a way that prepares students for their key exams? Concerns about evaluation emerged in discussions with teachers. Clearly, the nature of evaluation and accountability systems in the current context was not considered to support the wider use of IBSL. In this line, Crawford (2014) states that current assessment tools "do not achieve what is needed to give a good description of student performance and IBSE goals" (p. 4). The findings of this study suggest the need to review the evaluation system for better pedagogical alignment while promoting and including more explicit aspects of epistemic inquiry when evaluating students' learning. By considering teachers' views on IBSL, we explored how consistent these were with the three-sphere model discussed by Osborne (2014) and reflected upon science education standards (NRC, 2012).

A pedagogy aligned with this science education model ideally articulates three key processes: researching, constructing explanations and evaluating results to ensure coherence between the evidence and theories or models. Although teachers referred to IBSL as students developing their solutions through processes of inquiry and manipulation, no emphasis was placed on evaluating either alternative viewpoints and explanations or on the role of argumentation and modeling in science and technology within science education.

3.2.4. Goals of Research in Science Education

The findings previously reported going in tandem with the study of Capps *et al*. (2016), who identified a gap in self-reported frequency and knowledge about inquiry in science teachers. This raises the question of what constitutes inquiry. Therefore, teachers must be equipped with a good understanding of the key learning outcomes in science education and critical reflection on what type (or aspects) of IBSL support those learning goals. IBSL could be better conceptualized as "teachers engaging students in questioning, modeling, and communicating" ideas (Capps *et al*., 2016, p. 955) rather than some of the affective elements that teachers identified in this study. This will require greater efforts on science educators, those preparing the next and current generation of science teachers, to articulate more carefully and evince claims about IBSL. Additionally, evaluation pressures on teachers and accountability are barriers to successful implementation. Finally, the need for teachers to "cover the course program curriculum" presents an opportunity for design-led innovators to support teacher practice in the classroom (Oliver *et al*., 2019).

Finally, these need to branch the science research objectives into three directions. The first one is the evaluation of IBSL-based teaching models and strategies (Al-Ismaily *et al*., 2019; Maaß and Doorman, 2013; Moote, 2019). The second is the construction of instruments to measure the impact of teachers' and students' strategies and perceptions about IBSL (Aydeniz *et al*., 2021). And the last one is related to teachers' professional development (Capps and Crawford, 2013; Hamed *et al*., 2020; Ramnarain and Rudzirai, 2020).

4. CONCLUSIONS

The main objective of this study was to identify and analyze the core characteristics of the cycles of inquiry that are effective in physics learning processes at the university level. The literature review has shown that IBSL improves learning and understanding of science and its construction. Therefore, it could be considered that this premise is sustainable based on first-order factors that describe IBSL-centered teaching practice. This first exploration has provided us with valuable information about the teaching situation regarding implementing IBSL in the different courses of one bachelor's program in Physics. In particular, it is evident that the implementation of IBSL is highly influenced by the way science is assumed; that is when physics is conceived as a rigid, analytical, exact science or an experimental science where students' participation in IBSL activity is minimal. Likewise, the students were found to have at least one initial experience with IBSL. In addition, students prefer to apply IBSL in courses with greater conceptual and procedural complexity, such as quantum mechanics or electromagnetism. This is due to an interest in understanding the course-related phenomena. However, teachers' issues with IBSL's implementation will be explored in future research, especially regarding classroom management, resources, and system constraints. In conclusion, similar projects to this one would be interesting to receive support and help constitute effective professional development programs for teachers. This might mean the assurance of a greater number of students reaching important competencies, such as the ability to solve problems, self-study, and explore new areas of knowledge.

The combination of quantitative and qualitative data provided by this study casts an interesting picture of teachers' opinions on using research approaches. Participants highlighted the effects of IBSL on student motivation and engagement and referred to the positive impact of hands-on and manipulative experiences on learning. However, they did not refer to other cognitive or epistemic aspects, which are at the center of current science education research interpretations (Capps *et al*., 2016; NRC, 2012; Osborne, 2014). Additionally, teachers said they would like to use more IBSL but discussed the tensions between this approach and the currently established assessment curricula and teaching methods. They have called for greater systemic support and specific teacher training in this area while pointing out the need to strengthen teacher collaboration to implement classroom innovations. Drawing on the three-sphere model to interpret these results (NRC, 2012), our study reveals that teachers emphasize the research component of the inquiry about the dimensions related to the development and evaluation of explanatory models. This suggests the need to continue working on the dimensions related to explanation and assessment when conceptualizing and conducting inquiry in the classroom. Therefore, the results show limited use of these approaches and a somewhat unclear understanding of the pedagogical objectives.

Educationalimplications

Our study highlights the need to clarify IBSL purposes and aspects critical for its effective use in conjunction with the initial in-service teacher and professional development.

This study does not seek to produce a statistical generalization from sample to population but rather provides an analytical one (Plomp, 2013), which relies on the quality criteria of qualitative research since the focus is on developing a rich picture and a deep understanding. This is a small-scale study with a population of students and teachers who are already positively inclined towards IBSL. Therefore, the results may not be generalizable or applicable to other undergraduates or even to groups of university science teachers. After decades of political efforts to promote IBSL, this study contributes to the discussion of different types of inquiry while contrasting the views of teachers and students with science education standards through interpretations of how the inquiry should be operationalized to maximize learning benefits.

5. DECLARATIONS

5.1. Study Limitations

The study is limited to the sample size.

5.2. Acknowledgements

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5.3. Funding source

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5.4. Competing Interests

There are no conflicts of interest for conducting this research.

5.5. Open Access

6. HUMAN RELATED STUDIES

6.1. Ethical Approval

This research was approved by the Research Center, University of Antioquia. ID:070TT-2020.

6.2. Informed Consent (model used in the research)

I agree to voluntarily participate in this research, conducted by Tarcilo Torres Valois__ yes_. I have been informed that the goal of this study is to analyze the specific challenges posed by an open inquiry activity in the learning of physics_yes_.

I have been told about my actions and permissions as a student participating in the research.

I acknowledge that the information I provide in the course of this research is strictly confidential and will not be used for any purpose other than this study without my consent. I have been informed that I can ask questions about the project at any time, and that I can withdraw from it when I so decide, without this causing any harm to myself. If I have questions about my participation in this study, I can contact Tarcilo Torres Valois_ at the phone number 3105926719_ or at tarcilo.torres@udea.edu.co.

I understand that this consent form will be given to me, and that I may request information about the results of this study when it is completed. For this, I can contact tarcilo.torres@udea.edu.co_ at the aforementioned phone number.

Name of Student Participant Signature of Participant Date (in capital letters) printing)

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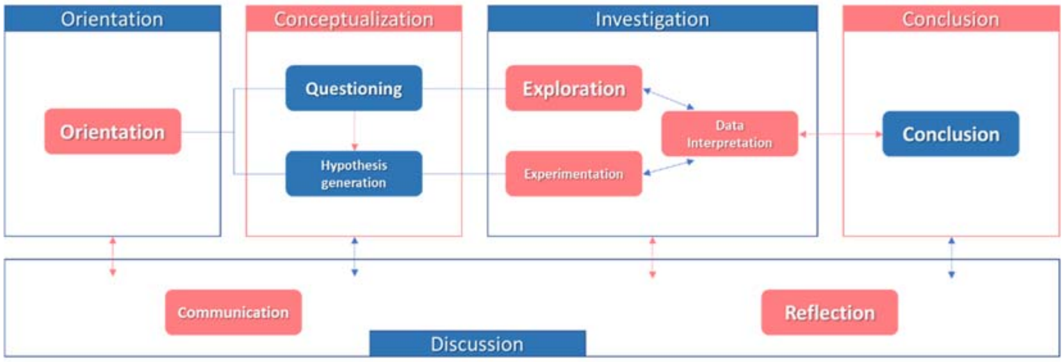

Figure 1. *Inquiry-based learning framework (general phases, sub-phases, and their relationships (Pedaste et al., 2015, p. 56).*

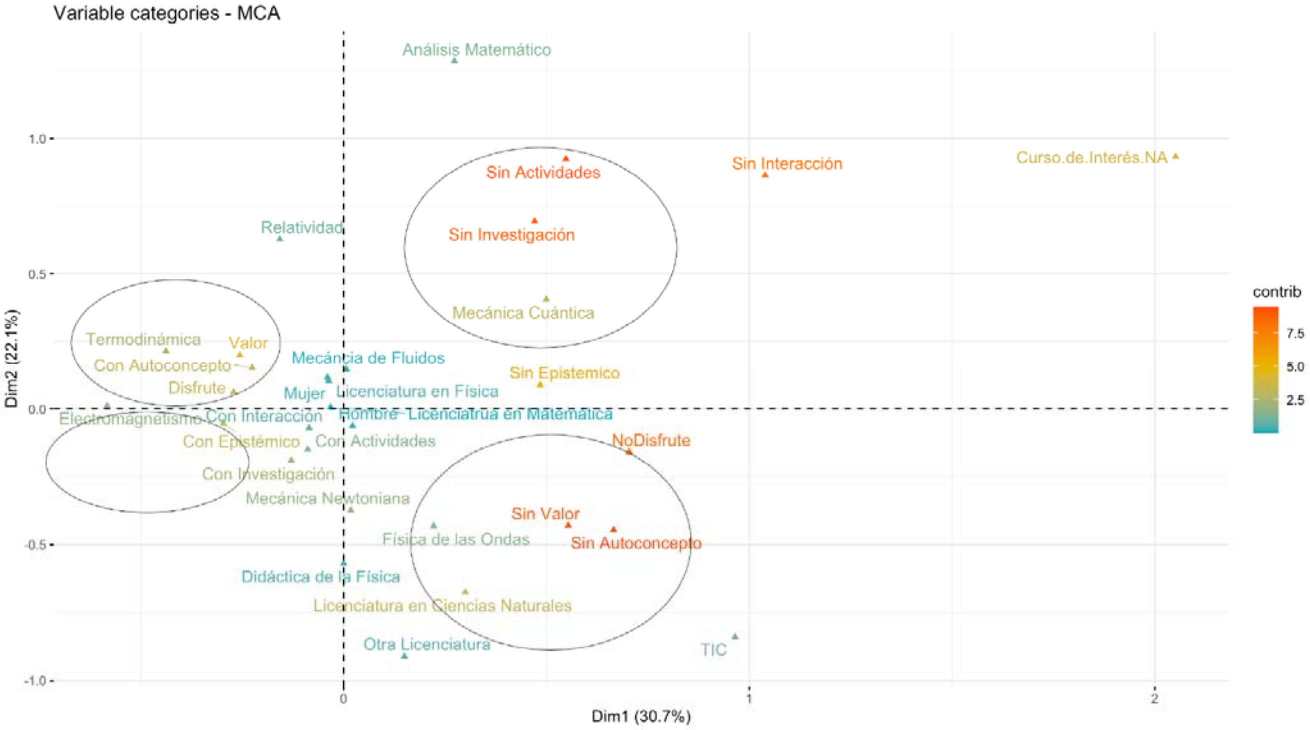

Figure 2. *Multiple correspondence analysis between the different categorical variables of the inquiry processes in physics classes*

Table 1. *Absolute and percentage distribution of the dimensions of inquiry according to the sex of the students of the Bachelor of Physics of the Faculty of Education of the UdeA; 2021*

IBSL Dimensions		***Sex***		***Value p****	***V of Cramér***
		Woman	***Men***		
Fun	strongly disagree	*1 (3,6%)*	*5 (9,8%)*	*0,701*	*0,128*
	In disagreement	*5 (17,9%)*	*11 (21,6%)*		
	Agree	***19 (67,9%)***	***30 (59,8%)***		
	Totally agree	*3 (10,7%)*	*5 (9,8%)*		
Inquiry value	strongly disagree	*4 (14,3%)*	*6(11,8%)*	*0,207*	*0,203*
	In disagreement	*4 (14,3)*	*11 (21,6%)*		
	Agree	***20 (71.4%)***	***30 (58,8%)***		
	Totally agree	*0 (0%)*	*0 (0%)*		
Autoconcepto	strongly disagree	*1 (3,6%)*	*4 (7,8%)*	*0, 204*	*0,203*
	In disagreement	*5 (17,9%)*	*19 (19,6%)*		
	Agree	22 (78.6%)	33 (64,7%)		
	Totally agree	*0 (0%)*	*0 (0%)*		
Self-concept	strongly disagree	*1 (3.6%)*	*6 (11.8%)*	*0.598*	*0.145*
	In disagreement	*8 (28.6%)*	*15 (29.4%)*		
	Agree	***16 (57.1)***	***26 (51.0%)***		
	Totally agree	*3 (10.7%)*	*4 (7.8%)*		
Epistemic interest	never or almost never	*3 (10.7%)*	*3 (5,89%)*	*0.897*	*0.089*
	in most classes	*10 (35.7%)*	*19 (37.2%)*		
	in some classes	*6 (21.4%)*	*11 (21.6%)*		
	Almost always or in all classes	*9 (32.1%)*	*18 (35.35%)*		
Hands-on	never or almost never	*6 (21.4%)*	*5 (9.8%)*	*0.128*	***0.268***
	in most classes	***11 (39.3%)***	***12 (23.5%)***		
	in some classes	*8 (28.6%)*	*24 (47.1%)*		
	Almost always or in all classes	*3 (10.7%)*	*10 (19.6%)*		
Investigation	never or almost never	*7 (25%)*	*10 (19.6%)*	*0.140*	*0.164*
	in most classes	*7 (25%)*	*9 (17.6%)*		
	in some classes	*9 (32.1%)*	*25 (49.0%)*		
	Almost always or in all classes	*5 (17.8%)*	*7 (13.7)*		

*Likelihood ratio test