Technology, Knowledge and Learning (2022) 27:879–890
https://doi.org/10.1007/s10758-021-09517-2

ORIGINAL RESEARCH

Methodological Elements for the Implementation of Data Acquisition Systems as Support for Experimental Activity in the Physics Teaching

Mónica Eliana Cardona Zapata[1] · **Sonia López Ríos**[1]

Accepted: 13 April 2021 / Published online: 19 April 2021

Abstract

Experimental activity in the physics teaching can be considered as a space in which teachers create contexts for students to approach the way scientific knowledge is constructed. In this sense, the strategies for the integration of Information and Communication Technologies (ICT) in the context of science education, has a wide potential to guide experimental activity to teachers in training. Among the tools offered by ICT, Data Acquisition Systems (DAS) favor to transform the image that students have, in terms of the technical-instrumental character of this science. This paper describes the potentialities of a heuristic V diagram designed as a theoretical-methodological tool that allows to increase the potential of DAS in the physics teaching; as well as the adaptation of the Learning Model in the Physics Laboratory Works (MATLaF), is proposed with the intention of recognizing the cognitive activities that students put into play to solve experimental situations in physics.

Keywords Conceptualization · V diagram · Data acquisition system · Experimental activity · Physics teaching · Teachers training

1 Introduction

The implementation of Data Acquisition Systems (DAS) in the physics teaching is proposed as a strategy that seeks to favor the process of conceptualization in experimental activity, understanding it as a space to design strategies that allow students to approach to the construction of scientific knowledge, taking into account that the theory–practice dialogue is encouraged and, mainly, that the construction of knowledge is collective; that is, as an alternative to traditional laboratory practices. In this process, the representation is constituted as a medium that allows, largely, capture the perceptions of people and, from the Vergnaud's Theory of Conceptual Fields, face increasingly complex situations developing

---

✉ Mónica Eliana Cardona Zapata
meliana.cardona@udea.edu.co
https://www.researchgate.net/profile/Monica_Cardona_Zapata

Sonia López Ríos
https://www.researchgate.net/profile/Sonia_Lopez30

[1] Education Faculty, University of Antioquia, St. 67 # 53-108, Medellin, Colombia

their schemes. In other words, the representation allows to reflect the necessary cognitive elements to be able to determine the procedures and the necessary information that allows to solve a situation, which according to Vergnaud are called operational invariants (Moreira, 2002). In this sense, the use of DAS is initially described as support for experimental activity in physics; later is presented the diagram adaptation AVM (Adaptation of the V Gowin Diagram for Computational Modeling) as a heuristic instrument proposed by Araujo et al. (2007) to perform activities of simulation and computational modeling in the physics teaching, in a critical and reflective way; and it is complemented with some contributions of the Vergnaud's Theory of Conceptual Fields (1990), to assess the process of conceptualization during experimental activity in the physics teaching with the support of DAS, calling it AVDAS diagram (Adaptation of the V Gowin Diagram for Implementation of Data Acquisition Systems). Finally, an archetype of the cognitive process is described in the laboratory based on the Learning Model in Physics Laboratory Works (MATLaF), designed by Andrés and Pesa (2004).

2 Use of Data Acquisition Systems in the Experimental Activity in Physics

The integration of Information and Communication Technologies (ICT) and specifically of the DAS in the teaching–learning process of physics in teacher training programs, has as main purpose to address a problem related to experimental activity in these programs; which has its fundaments on the vision of different authors (Ayala, 2006; Cortés & de la Gándara, 2007; Antúnez et al., 2008; Pérez & Segura, 2010; Ribeiro & da Silva, 2013; Andrés et al., 2008; Romero et al., 2011; Medina & Tarazona, 2011), who agree that the experimental activity is a space in which teachers can create contexts for students to approach the way scientific knowledge is constructed. However, according to Cortés and de la Gándara (2007), citing Hodson (1985), the image that many teachers and students have of experimental activity is that they are spaces for the manipulation of instruments or the application of exercises outside of some conceptual content, with a previously defined procedure. Therefore, they support the idea that it is convenient that said activity contributes to the construction of knowledge, from the interaction between teachers and students, with the conceptual content, the procedural aptitudes, resolution of problems and the discussion generated between the same students. In this sense, "experimentation and observation will serve to learn, only if they cause the students to ask questions, that is, if it leads to represent possible interpretations of what is observed, to be able to discuss them" Sanmartí (2002) cited in (MEN, 2006, p. 436).

For future physics teachers, it can be take into account the contributions of Hodson (1994), in terms of promoting the re-contextualization of experimental practice, focused on the realization of experiences that help students to approach the construction of scientific knowledge, and to conceive this space as "optimal for the interrelated learning of the methodological domains and of meanings, as well as for the development of a vision about experimental activity according to actual epistemological positions" (Andrés et al. 2006; p. 343). Likewise, involving teachers in training in the design of experimental activities, favors their participation in the construction of scientific knowledge, allowing them to generate alternatives for their work (Medina & Tarazona, 2011).

In the context of physics teaching, some authors (Pontes, 2005; Grisolía, 2009; Capuano, 2011; Macêdo et al., 2014; da Silva & Khalil, 2015) consider that ICT have been incorporated increasingly in the educational sector, helping to improve teaching and learning processes; however, there is little reflection on learning theories or didactic strategies that accompany their implementation and provide tools to articulate different student thinking processes in the approach to the construction of scientific knowledge. In addition, these tools play an important role in the development of experimental activities, since they help to overcome teaching based on theoretical classes; since the use of real or virtual experiments is a way of "awakening curiosity, stimulating scientific debate and improving students critical thinking" (de Macêdo et al., 2014, p.188).

For the use of the computer in this specific area is found, in the majority of works of computational tools implementation, diverse possibilities such as data processing, development of graphs, the use of instruments of acquisition and processing data, the realization of simulations and computational modeling of physical phenomena. Among these modalities, the collection and analysis of data in real time through DAS is highlighted; which have been little explored for the physics teacher training in particular, and constitute tools that support the experimental activity in the process of information collection and of performing calculation, allowing more time to be dedicated to conceptualization process. In sciences in general and in physics in particular, computational tools have served to create complex scientific models, which could not be achieved manually. The importance of this tool in the scientific field can be extrapolated to the teaching of science field, where it is necessary to prepare students to meet the technological demands of today.

According to Haag et al. (2005, p. 69), "among the diverse applications of information and communication technologies in the education of citizens, we especially emphasize two in the teaching of science: the computer as a tool for scientific modeling and to support the laboratory". In this second aspect, DAS are considered as an alternative so that through experimentation supported by this tool a wider image of the phenomenon to be studied can be provided, by having graphics almost immediately, showing the relationship between variables involved in the situation. In addition, as mentioned by Pontes et al. (2006), the use of DAS "contributes to the development of manual skills (assembly, measurement) and intellectual abilities or scientific skills (ability to observe and express, order, perseverance, recognition of errors, representation and data analysis…) that offer an opportunity of manifest much greater than other activities, such as problem solving" (p. 264).

As shown in Fig. 1, a DAS is formed by a measuring device that allows experimental data obtained with sensors of diverse physical magnitudes to be read automatically, stored and analyzed by a computational *software* (Gil & Rodríguez, 2001, cited in Pontes et al., 2006). The *software* as such, allows to process and monitor the variables of a physical system in real time, while the sensors are "devices with internal characteristics directly affected by an external phenomenon (parameter), and, therefore, there is a direct relationship between them. The external phenomenon can be temperature, humidity, pressure, etc., and the internal characteristic can be, for example, resistance or capacitance "(Martins &

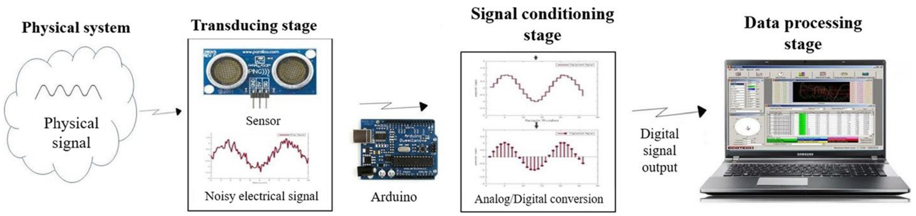

Fig. 1 Stages of a Data Acquisition System (Cardona & López, 2017, p. 3)

Viana, 2011, p. 657). That is to say, through sensors the quantity to be measured is transformed into an electrical signal, this signal is sent to a circuit called interface, which transforms it into a sequence of digital values of voltage or current that are read, processed and stored by the computer. All data acquisition system requires a sensor to convert some physical quantity—such as temperature, force, pressure—into an electrical signal that is then supplied to the computer for data collection and analysis (Haag et al., 2005).

From the perspective of the previous authors, DAS can help to set aside laboratory practices type recipe to introduce open activities, which are potentially more auspicious for learning concepts of a physical phenomenon to be studied. In this sense, according to Pontes et al. (2006), "the use of computers in laboratories also simplifies the tedious task of carrying out many measurements, because the data acquisition system can perform measurements in an extremely fast way, which facilitates the access to unimaginable experiences some years ago, or that were carried out so slowly that it would be tedious for the students" (p. 264).

On the other hand, it is necessary that students appropriate of these sensors and different software that allows the collection of data, so that they do not become a black box and can be used in the best way. In addition, with the support of this tool the assemblies used in conventional experimentation are not left aside, since they are required to make the measurements through the sensors, and it is the acquisition system that allows to represent the data obtained at a much greater velocity, leaving the student analysis and interpretation of results; as well as the possibility of repeating the measurements as many times as it considers necessary to immediately see their effects.

3 AVDAS Diagram for the Implementation of DAS as Support for Experimental Activity in the Physics Teaching

With the intention of knowing the conceptualization process of the students, when they face a situation proposed in an experimental activity in physics, oriented with the use of DAS, an adaptation of the AVM diagram with the components presented in Fig. 2 is proposed.

As is shown in Fig. 2, AVDAS diagram is an instrument that consist of three related parts:

1. In the central part is the purpose of the experimental activity, which refers to the objectives, the questions, and the situation under study. The objectives are related to what is intended to be achieved in the experimental activity oriented from the DAS, which is related to a particular situation associated with a conceptual field that is to be studied; this situation is described in the vertex of the V, and its definition is taken from the Theory of Conceptual Fields, as a set of complex tasks that give meaning to the concepts. The questions refer to those issues that will be answered from the implementation of the DAS and that seek, in agreement with Araujo et al. (2012), to be key points to favor meaningful learning; always that is avoided procedural questions that only require algebraic manipulation or the calculation of numerical values.
2. On the left is the conceptual domain, conformed by the conceptual field, theories/principles/theorems/laws/concepts, the physical system components, the variables, procedures, constants and their representations, mathematical relations, known results and student predictions. The first two elements are taken as a contribution of the theoretical

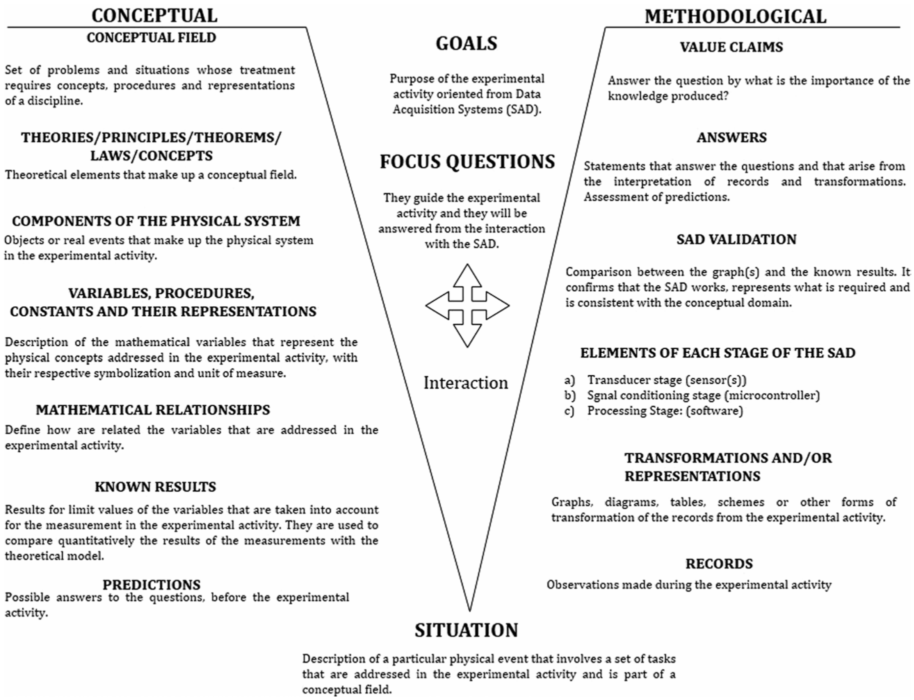

Fig. 2 AVDAS diagram for the implementation of DAS in experimental activity in the physics teaching

reference of learning, the Theory of Conceptual Fields, given that in the context of experimental activity it is essential to identify the referential framework from which one hopes to learn. It is important to point that the notion of the concept of system is of great importance when we refer to physics as an experimental science, which is based on models and allows us to approach to physical situations to find a solution under an existing theoretical framework (Covaleda et al., 2005). Therefore, in the physical system components all elements that are part of the experimental activity are described and that the student considers that play an important role in facing a situation. On the other hand, the variables, procedures, constants and their representations, the mathematical relations and the known results, are elements that are extracted from the theoretical framework to which the conceptual field is associated, from which a level of domain is required by the students, that allows the development of experimental activity in permanent interaction with the methodological domain. Finally, predictions are taken as an initial attempt to answer the questions before facing the situation; at this point it is essential that students explain the reasons on which their beliefs are based, in such a way that they are aware of the importance of previous knowledge for their interpretations.

3. On the right, is the methodological domain that includes the registers, transformations and/or representations, the own elements of the DAS stages, the DAS validation, answers to the questions and assertions of value. The registers indicate the observations that are carried out in the attempt to answer the questions, taking into account variables and parameters that are used to represent the physical system, as well as the known, student results and predictions. In the transformations and/or representations an organi-

zation of the registers is carried out, by means of tables, graphs, diagrams, drawings or another type of representation that is necessary to understand the process of student conceptualization. The following space corresponds to the own elements of each of the DAS stages; in the transducer stage, the type of sensor used to carry out the measurements is identified, in the signal conditioning stage, the analog–digital converter or the used microcontroller is mentioned and in the processing stage the software or application in charge of the numerical processing corresponding to each particular experiment is indicated. This characterization is carried out with the purpose that students identify the used DAS as part of the experimental activity and not as a measurement instrument of which they do not know how it works.

Next, a fundamental element of the diagram is presented, which is the DAS validation, in this field, students are expected to compare the graphs and known results with those obtained during the experimental activity, and generate arguments in relation to the reliability of the DAS used and its coherence with the conceptual domain. After this validation, the answers to the questions that guided the activity are presented, based on the interpretation of the registers and their transformations, and making a comparison with the predictions made. In this space, according to the Theory of Conceptual Fields, the predicative form of student knowledge is valued, that is, the way they put into words their understanding of the situation. The last component of the diagram answers the question: what is the importance of the produced knowledge? With this, it is intended that students value the possibilities of the implementation of DAS during experimental activity and its role to face a proposed situation; besides to indicate the modifications that can be made, or how it can be related to other situations that allow to improve their degree of domain of the conceptual field addressed.

The diagram presented in Fig. 2, is presented as a theoretical-methodological tool that allows to increase the potential of DAS in the physics teaching, enabling its critical use and providing a means by which it is possible to assess the process of student conceptualization. In this sense, it is considered that the use of this diagram helps to enhance the contribution of DAS to the conceptualization in physics and experimental activity.

4 Model for the Analysis of the Cognitive Process in Experimental Activity

About the cognitive process in experimental activity, the main ideas of the MATLaF, designed by Andrés and Pesa (2004), were resumed. This model was developed within the framework of the Vergnaud's Theory of Conceptual Fields (1990), with the purpose of recognizing the cognitive process that occurs during a laboratory work from a novel situation. The MATLaF and its process is represented in Fig. 3.

According to Fig. 3, the laboratory work starts from a situation not known by the students, which is perceived by the schemes presents in their cognitive structure; by not finding a solution that fits the situation, the operational invariants are activated, from which mental models are constructed, which evolve recursively along with predictions and inferences, until find their functionality. In the process of elaborating mental models, with their underlying invariants, initial goals are generated, which trigger rules of action specific of the experimental activity; these rules allow interpreting and contrasting predictions and inferences, which once considered pertinent, it can be affirmed that the goal has been

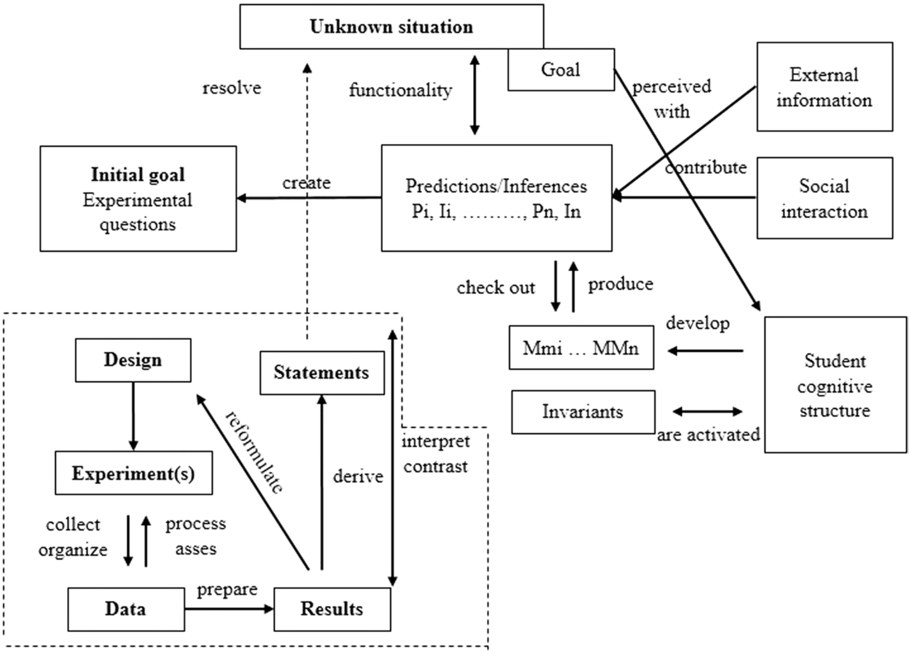

Fig. 3 Dynamic model of Learning in Physics Laboratory Works (Andrés et al., 2006; own translation)

reached. In this process, social interaction, the search for external information, teacher mediation, realization of observations, among others, play a fundamental role; which contributes to the adaptation of the schemes to novelty and variety (Andrés et al., 2006).

By guiding the experimental activity from this learning model, three main moments are proposed for the collection of information: diagnosis, intervention and evaluation of the level of final conceptualization. These three moments are framed in four phases proposed in the MATLaF, namely:

1. Identification of initial operational invariants of students, associated to the conceptual field.
2. Identification of operational invariants of students, associated strictly with experimental subtasks.
3. Evaluation of the achievements learned.
4. Comparison of the student (and teacher) expectations with the achievements obtained.

5 Articulation Between the AVDAS Diagram and the MATLaF

In order to articulate the AVDAS diagram design and the MATLaF, Table 1 presents a parallel between the meeting points of both methodological tools for its implementation in the experimental activity; in addition, a proposal based on the Vergnaud's Theory of Conceptual Fields (1990) is briefly described, which allows identifying the main characteristics of

Table 1 Articulation between the AVSAD diagram and the MATLaF

MATLaF	AVDAS Diagram
Presentation of a situation not known by students	Particular physical event that involves a set of complex tasks that are addressed in experimental activity and allow to approach to a conceptual field
Activation of operational invariants and construction of initial mental models	Elaboration of predictions as possible answers to questions of the experimental activity and development of the conceptual domain
Generation of initial goals that trigger rules of action specific to experimental activity	Appropriation of the objectives and development of the methodological domain from data register, transformations and representations, and the validation of the DAS to answer the questions
Contrasting the predictions and inferences with results to determine if the goal has been reached	Answers to the questions that guide the experimental activity and assertions of value to determine the importance of the produced knowledge

experimental activities oriented with DAS during the training of science teachers, as well as the role of this tool in the conceptualization processes of students.

5.1 A Proposal for the Implementation of DAS as Support for Experimental Activity in the Physics Teaching

Figure 3 represents the proposal based on the MATLaF (Andrés & Pesa, 2004), which was developed to identify the cognitive development of students when faced with novel

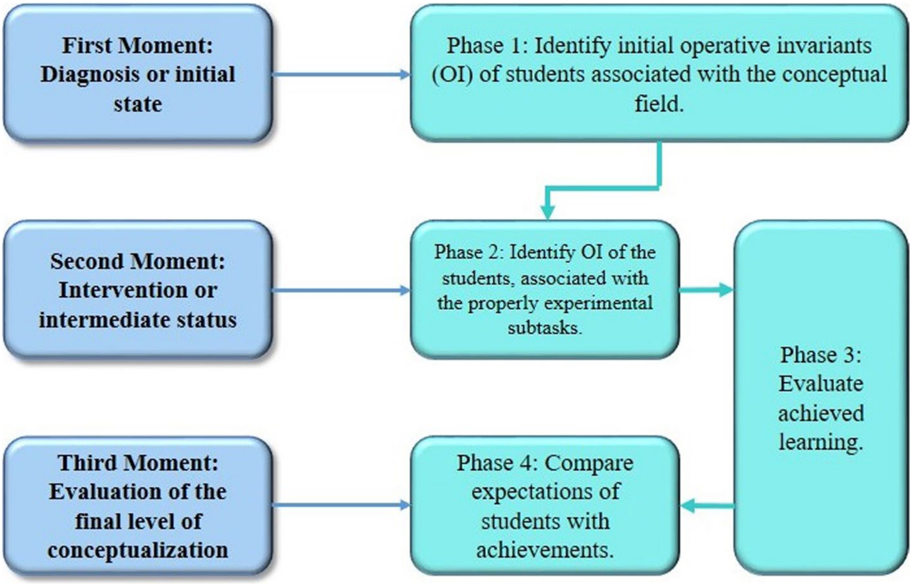

Fig. 4 Moments and phases of the methodological propose

Table 2 Moments for the collection of information in the cognitive process model during the experimental activity

Moment	Porpuse	Phase
Diagnosis or initial state	Infer the initial Operational Invariants (OI) of students	Identify initial Operational Invariants (OI) of students associated with the conceptual field
Intervention or intermediate state	The analysis of this information would allow obtaining evidence about: (1) the assimilation schemes used by students in front of those subtasks that were known (2) the subtasks that are unknown to them and the OI underlying the constructed scheme to address them (3) the symbolic representations that they produce in relation to concepts and the situation	Identify student OI, associated with strictly experimental subtasks
E valuation of the final conceptualization level	Establish the scope of the intervention, in terms of change between initial and final state	Evaluate the learning achieved
	Become aware of the learning that is expected to be achieved, reflect about the achievements and possible discrepancies	Compare students expectations with achievements

experimental situations. From this model, three moments are presented with defined purposes for the collection of information that are summarized in Fig. 4.

Based on the methodological proposal, Table 2 presents the main purposes of each of the moments, in order to guide the design of experimental activities that are implemented using these methodological tools for students of teacher training programs in natural sciences.

6 Final Considerations: Implications for the Teaching

The methodological resources proposed in this article to accompany the implementation of DAS in experimental activity, play a fundamental role by allowing to identify the cognitive processes that students put into play to solve novel situations. Mainly, through the diagram, enunciation is favored, an element that is essential in the process of conceptualization, and consists in the externalization of the relationship between forms of knowledge, categorized by Vergnaud, as the operative and predicative forms. Analysis of the process of student conceptualization necessarily implies propitiating spaces so that they can make their representations explicit, which is achieved thanks to the articulation of both tools and to the permanent insistence so that the students reflect on everything that implies facing a situation. In this way, one of the main implications of this proposal is to favor the critical capacity about the study object, the evolution in laboratory perception, the complementary character of the theory–practice relationship and the analysis of an experiment structure.

In the same way, understanding the conceptualization in physics as a process that is part of the cognition of human being, and in which situations and schemes present in the cognitive structure of a subject are in permanent interaction, it can be affirmed that the use of DAS contributes considerably to this process, by allowing students to identify relationships between variables based on the interpretation of graphs; what influences the rules of action and the selection of pertinent information to face the proposed situations. In the same way, comprehension of whole process of data acquisition, from the measurement with sensors, until obtaining the data in the computer, reduces the uncertainty of students to solve problems; emerging knowledge in action that reflects the adaptation of its schemes to novelty.

This allows us to affirm that there are alternatives such as the proposal described in this article, which seek to promote the transformation of the technical-instrumental image of the physics teaching, making use of the DAS not only as a tool with a merely instrumental character, but that helps to reflect on the way in which concepts are constructed from experimentation; establish relationships between daily life and scientific models, and from the approach of novel situations, spaces are provided to bring students to the construction of scientific knowledge, largely thanks to the characterization of the theoretical and methodological domains involved in such situations.

Acknowledgements We thank the Committee for the Development of Research (CODI) of the Antioquia University and its program called Social Sciences, Humanities and Arts 2016, for the total funding of the research project that gives rise to this study.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

References

Andrés, M. M., & Pesa, M. (2004). Conceptos-en-acción y teoremas-en-acción en un trabajo de laboratorio de física [Concepts-in-action and theorems-in-action in a physics laboratory work]. *Revista Brasileira de Pesquisa em Educação em Ciências, 4*(1), 59–75

Andrés, M. M., Pesa, M., & Meneses, J. (2006). La actividad experimental en Física: Visión de estudiantes universitarios [Experimental activity in Physics: Vision of university students]. *Paradigma, 17*(1), 349–363

Antúnez, G., Pérez, S., & Petrucci, D. (2008). Concepciones de los docentes universitarios sobre los trabajos prácticos de laboratorio [Conceptions of university professors about practical laboratory work]. *Revista Brasileira de Pesquisa em Educação em Ciências, 8*(1), 1–17.

Araujo, I., Veit, E., & Moreira, M. (2007). Um estudo exploratôrio sobre as potencialidades do diagrama AVM na aprendizajem significativa de tópicos de Física [An exploratory study on the potentialities of the AVM diagram in the significant learning of physics topics]. *Indivisa: Boletín de Estudios e Investigación, 8*, 503–514

Araujo, I., Veit, E., & Moreira, M. (2012). Modelos computacionais no ensino-aprendizagem de física: um referencial de trabalho [Computational models in the teaching-learning of physics: a referencial work]. *Investigações em Ensino de Ciências, 17*(2), 341–366

Ayala, M. (2006). Los análisis histórico-críticos y la recontextualización de saberes científicos. Construyendo un nuevo espacio de posibilidades [Historical-critical analysis and the recontextualization of scientific knowledge. Building a new space of possibilities]. *Pro-Posições, 17*(1), 19–37

Capuano, V. (2011). El Uso de las TIC en la Enseñanza de las Ciencias Naturales [The use of ICTs in natural sciences teaching]. *Virtualidad Educación y Ciencia, 2*(2), 79–88

Cardona, M. E., & López, S. (2017). A literature review about data acquisition system in physics education in middle and high school levels, and in teacher training. *Revista Brasileira de Ensino de Física, 39*(4), e44041–e440411

Cortés, A., & De la Gándara, M. (2007). La construcción de problemas en el laboratorio durante la formación del profesorado: una experiencia didáctica [The construction of problems in the laboratory during teacher training: A didactic experience]. *Enseñanza de las Ciencias, 25*(3), 435–450

Covaleda, R., Moreira, M., & Caballero, M. (2005). Los significados de los conceptos de sistema y equilibrio en el aprendizaje de la mecánica. Estudio exploratorio con estudiantes universitarios [The meanings of the concepts of system and balance in the learning of mechanics. Exploratory study with university students.]. *Revista electrônica de enseñanza de las ciencias, 4*(1), 1–27

da Silva, F., & Kalhil, J. (2015). Tecnologias digitais computadorizadas contribuem com o ensino de Física? [Digital computer technologies contribute to the teaching of physics?]. *Latin-American Journal of Physics Education, 9*(1), 1501-1-1501–17

de Macêdo, J., Pedroso, L., Voelzke, M., & de Araújo, M. (2014). Levantamento das abordagens e tendências dos trabalhos sobre as Tecnologias de Informação e Comunicação [Survey of the approaches and tendencies of the works on the information and communication technologies]. *XIX Simpósio Nacional de Ensino de Física En Caderno Brasileiro de Ensino de Física, 31*(1), 167–197

Grisolía, M. (2009). Incorporando Tecnologías de la Información y la Comunicación en un curso de Física General [Incorporating information and communication technologies in a general physics course]. *Latin-American Journal of Physics Education, 3*(2), 439–445

Haag, R., Araujo, I., & Veit, E. (2005). Por que e como introduzir a aquisição automática de dados no laboratório didático de física? [Why and how to introduce automatic data acquisition in the physics teaching laboratory?]. *Física na Escola, 6*(1), 69–74

Hodson, D. (1985). Philosophy of science, science and science education. *Studies in science education, 12*(1), 25–57

Hodson, D. (1994). Redefining and reorienting practical work in school science. In R. Levinson (Ed.), *Teaching science* (pp. 159–163). The Open University.

Martins, J., & Vianna, A. (2011). Teaching general concepts about sensors and transfer functions with a voltage divider. *Latinoamerican Journal of Physics Education, 5*(4), 656–666

Medina, J. & Tarazona, M. (2011). *El papel del experimento en la construcción del conocimiento físico, el caso de la construcción del potencial eléctrico como magnitud física. Elementos para propuestas en la formación inicial y continuada de profesores de física* [The role of the experiment in the construction of physical knowledge, the case of the construction of the electric potential as a physical quantity. Elements for proposals in the initial and continuing training of physics teachers]. (Master's thesis) University of Antioquia, Colombia (2011).

Ministerio de Educación Nacional. (2006). Estándares básicos de competencias en matemáticas [Basic competency standards in mathematics]. Bogotá.

Moreira, M. (2002). La teoría de los campos conceptuales de Vergnaud, la enseñanza de las ciencias y la investigación en el área [The theory of the conceptual fields of Vergnaud, the teaching of science and research in the area.]. *Investigaciones en Enseñanza de las Ciencias, 7*(1), 1–28

Pérez, J., & Segura, A. (2010). Discusión acerca de la utilidad e importancia de los laboratorios de física en la enseñanza actual [Discussion about the usefulness and importance of physics laboratories in current education]. *Góndola, Enseñanza y Aprendizaje de las Ciencias, 5*(1), 43–47

Pontes, A. (2005). Aplicaciones de las tecnologías de la información y de la comunicación en la educación científica. Segunda parte: aspectos metodológicos [Applications of information technology and communication in science education. Second part: Methodological aspects]. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias, 2*(3), 330–343

Pontes, A., Gavilán, J., Obrero, M., & Flores, A. (2006). Diseño y aplicación educativa de un programa de simulación para el aprendizaje de técnicas experimentales con sistemas de adquisición de datos [Design and educational application of a simulation program for the learning of experimental techniques with data acquisition systems]. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias, 3*(2), 251–267

Ribeiro, J., & da Silva, M. (2013). Uma investigação da influência da reconceitualização das atividades experimentais demonstrativas no ensino da óptica no ensino médio [An investigation of the influence of reconceptualization of demonstrative experimental activities of optics in high school]. *Investigações em Ensino de Ciências, 18*(2), 239–262

Romero, A., Aguilar, Y., Medina, J. & Tarazona, M. (2011). *La experimentación y el desarrollo del pensamiento físico: un análisis histórico y epistemológico con fines didácticos* [The experimentation and the development of the physical thought: a historical and epistemological analysis with didactic aims]. Medellin: University of Antioquia.

Vergnaud, G. (1990). La teoría de los campos conceptuales [The theory of conceptual fields]. *Recherches en didactique des mathématiques, 10*(2), 3