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The relationship between epistemological beliefs and the performance of high school students in Physics investigative activity[1]

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ABSTRACT
This work aims to identify the relationship between students' epistemological conceptions and their performance in an investigative activity, carried out in pairs, through a computer simulation. The students' performance was evaluated according to a set of factors: the total number of experiments carried out, the exploration of the experimental field, the percentage of independent variables researched; and the quantity and/or percentage of valid and conclusive tests performed. 184 first-year high school students from a federal public school in Belo Horizonte participated in this quantitative research. The results suggest that, in general, students who have more sophisticated epistemological beliefs about the Nature of Science tend to present more appropriate strategies for controlling variables and experimentation. Based on the results obtained, educational implications are discussed and new research possibilities in the area are proposed.
KEYWORDS: Science Education. Investigative activities. Nature of Science.

A relação entre as crenças epistemológicas e o desempenho de estudantes do Ensino Médio em atividade investigativa de Física

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RESUMO

Esse trabalho tem como objetivo buscar identificar a relação entre as concepções epistemológicas dos estudantes e o seu desempenho em uma atividade investigativa, realizada em duplas, por meio de uma simulação computacional. O desempenho dos estudantes foi avaliado segundo um conjunto de fatores: o total de experimentos realizados, a exploração do campo experimental, a percentagem de variáveis independentes pesquisadas; e a quantidade e/ou percentagem de testes válidos e conclusivos realizados. Participaram desta pesquisa quantitativa 184 alunos do primeiro ano do Ensino Médio de uma escola pública federal de Belo Horizonte. Os resultados sugerem que, no geral, alunos que apresentam crenças epistemológicas mais sofisticadas sobre a natureza da ciência tendem a apresentar estratégias mais adequadas de controle de variáveis e de experimentação. Com base nos resultados obtidos, são discutidas as implicações educacionais e propostas novas possibilidades de pesquisa na área.

PALAVRAS-CHAVE: Educação em Ciências. Atividades investigativas. Natureza da Ciência.

La relación entre las creencias epistemológicas y el desempeño de estudiantes de secundaria en la actividad investigativa en Física

RESUMEN

Este trabajo tiene como objetivo identificar la relación entre las concepciones epistemológicas de los estudiantes y su desempeño en una actividad investigativa, realizada en parejas, a través de una simulación por computadora. El desempeño de los estudiantes fue evaluado según un conjunto de factores: el número total de experimentos realizados, la exploración del campo experimental, el porcentaje de variables independientes investigadas; y la cantidad y/o porcentaje de pruebas válidas y concluyentes realizadas. De esta investigación cuantitativa participaron 184 estudiantes de primer año de secundaria de una escuela pública federal de Belo Horizonte. Los resultados sugieren que, en general, los estudiantes que tienen creencias epistemológicas más sofisticadas sobre la naturaleza de la ciencia tienden a presentar estrategias más apropiadas para el control de variables y la experimentación. A partir de

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los resultados obtenidos, se discuten implicaciones educativas y se proponen nuevas posibilidades de investigación en el área.

PALABRAS CLAVE: Enseñanza de las Ciencias. Actividades investigativas. Naturaleza de la Ciencia.

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Introduction

The curricular incentive for students' understanding about the nature of science (NOS) had its origins at the beginning of the 20th century, right when science gained a space within the school curriculum. Matthews (1998) cites arguments from John Dewey and Ernst Mach about the importance of understanding the scientific method, highlighting that its comprehension would be more important than the acquisition of scientific knowledge itself.

With the expansion of the curricular objectives from the beginning of the 90s, there was an emphasis that the understanding of scientific knowledge should not be limited to the simple mastery of formulas, facts, laws and scientific theories, but should also be composed of greater knowledge about the NOS and the process of producing new knowledge. Educators and researchers then began to stand up for the use of activities that deal with NOS explicitly and that present a model of ‘doing science’ that is more valid from a philosophical and epistemological point of view (Hodson, 1988; Lederman; Lederman, 2014; Mccomas, 2020; Taber, 2017). The argument is that:

> […] teaching about the nature of science is essential to a science education that wishes to prepare future scientists, cultured members of society, and informed citizens, and that accordingly great care is needed to balance the teaching about science itself as a cultural and intellectual activity, and teaching about some of the

> important, fascinating, and highly applicable, scientific knowledge that this cultural activity we call science has produced (Taber, 2017, p. 26).

The preparation of pedagogical activities with an investigative approach and the involvement of students in scientific practices that allow them to experience the process of building scientific knowledge can help them establish connections between the nature of science, its concepts and procedures (Carvalho, 2018; Manz; Lehrer; Schauble, 2020; Zômpero; Laburú, 2011).

However, researchers defend the hypothesis that students' understanding of the NOS, especially their epistemological beliefs, may affect their actions and decisions during educational activities, especially in practices related to investigative activities (Deng *et al.*, 2011; Lin; Zhu; Chan, 2023; Mete, 2023; Wu; Wu, 2011).

In this paper, epistemological beliefs refer to students' ideas, beliefs and conceptions about how scientific knowledge is produced, developed and justified, involving specific aspects and assumptions about the NOS (Sandoval, 2005). Therefore,

> [...] provides a rationale for the procedures and practices in which scientists engage, a knowledge of the structures and defining features that guide scientific enquiry, and the foundation for the basis of belief in the claims that science makes about the natural world (OECD, 2016, p.30).

During the investigative activities, some epistemological themes are particularly important and may significantly influence students' strategies when carrying out the activity. These themes include the relationship between the individual's knowledge and the data available, the purpose of the activity developed, the ways in which the evidence may or may not support certain statements or proposed hypotheses, the relationship between these

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hypotheses and the quality of the data collected, etc. However, the difficulties of research in the area are great. There is still little information about how these epistemological beliefs affect students' reasoning and actions during practical activities or, even, which epistemological beliefs students use to build their own scientific knowledge. Furthermore, research results indicate that a large part of students' ideas about the experimentation process and, above all, their epistemological beliefs, seem diffuse, not very coherent and tacit (Barzilai; Zohar, 2014; Gomes, 2009; Wu; Wu, 2011).

Therefore, "there is a gap between what is known about students' inquiry practices and their epistemological beliefs about science" (Sandoval, 2005, p. 634). Thus, this work seeks to obtain elements for a better theoretical and practical understanding of the influence and relationship between students' epistemological beliefs and their performance in an investigative activity. Its objective is to answer the following questions:

1) Is there a relationship between epistemological beliefs and students' experimental performance during an investigation?

2) Is it possible to identify patterns in students' epistemological beliefs and relate them to their experimental performance during the activity?

Epistemological beliefs

Despite the extensive literature on the view that teachers and students have on science, the production and development of scientific knowledge (Lederman; Lederman, 2014; Mccomas, 2020), there are relatively fewer studies that have focused on how these beliefs influence actions of students during their learning process.

Regarding this possible influence, Driver and collaborators state that

> […] often, it seems as though learners' responses to observations and ideas are constrained and limited in significant ways by their perception of the nature of scientific work and of scientific

> knowledge itself. The result is that new experiences and information presented in the classroom and laboratory are often interpreted by students in ways that differ from those intended by teachers and curriculum planners. Knowing more about these perceptions may, therefore, help us to understand better the processes of science content learning and hence contribute to more effective teaching (Driver *et al.*, 1996, p. 2-3).

In his extensive review of research literature on the history and philosophy of science, Duschl (1994) sustains the statement that individuals, from the first years of life, build explanations about various natural phenomena and that these are guided by epistemological models. Carey and collaborators (1989) also believe that students' performance during various activities is influenced by their perceptions regarding the process of building scientific knowledge. Hogan (2000) proposes changing the question from what students' conceptions about the nature of science are to what these conceptions influence and how they change during students' academic lives.

Such a change in focus is not a tendency to consider other aspects of scientific practice less important, but rather,

> [...] this narrower, more clearly epistemological focus seems appropriate for a consideration of the role that students' inquiry may play in developing their understanding of the practice of science, and on understanding how students' ideas about the nature of knowledge and the means for generating it may influence their inquiry (Sandoval, 2005, p. 638).

In the last two decades, work on individuals' epistemological beliefs has intensified, becoming a prominent line of research in the field of education. Psychologists and researchers in the area of human cognition also incorporated the notion of epistemology and internalized this concept, defining a personal epistemology, which would be a set of beliefs and knowledge that individuals possess and develop about the nature of knowledge, its production and acquisition, which may act as a standard for judging the validity of claims and evidence.

Researchers, in this psychological perspective, agree that epistemological beliefs are related to cognition, metacognition, motivation, learning and understanding, directly or indirectly influencing problem-solving strategies and student performance in various activities. Several studies provide evidence of these relationships (Barzilai; Zohar, 2014; Carey; Smith, 1993; Lin; Chiu, 2004; Lising; Elby, 2005; Stathopoulou; Vosniadou, 2007).

Edmondson and Novak (1993) state that there is a very strong interaction between students' epistemological knowledge and their learning strategies, that is, the authors defend the existence of a dynamic relationship between individuals' conceptions about the structure and origin of scientific knowledge and their approaches and techniques used to learn science.

Sandoval (2005) uses the term formal epistemology to refer to the set of ideas and conceptions that individuals have about scientific knowledge, its production and validation through professional science and the actions of scientists. The author also uses the term practical epistemology to refer to the set of ideas and conceptions that students have about the production of their own knowledge at school, during science learning – the epistemological beliefs that guide their practice. Put in other words,

> […] practical epistemology involves the ideas for the nature of scientific knowledge, the approach of producing scientific knowledge, and the criteria of evaluating scientific knowledge claims that could reflect students' decision and criteria of the construction and evaluation of scientific knowledge in their own learning practices (Wu; Wu, 2011, p.322).

These beliefs are about what knowledge is, the individual's methods for producing it, and the criteria for evaluating it. Sandoval (2005) also warns that when we refer to epistemology as beliefs and conceptions, the idea that may be passed on is of a set of coherent and explicit beliefs. However, the author argues that such conceptions can perfectly manifest themselves implicitly and are often tacit in nature. His objectives in drawing this distinction are to defend the thesis that such epistemological knowledge is different and to explain the difficulty in changing individuals' conceptions of formal epistemology only with science classes.

Methodological aspects

The research carried out was quantitative in nature and the activities involved allowed participants to engage in three scientific practices: (i) formulating questions and hypotheses; (ii) planning and carrying out investigations; (iii) data analysis and interpretation (Vorholzer; Von Aufschnaiter; Boone, 2020).

184 students from seven first-year high school classes at a federal public school in Belo Horizonte participated in the research, with ages ranging between 15.1 and 18.3 years old and an average of 16.2 years old.

Although this research has not been submitted to an Ethics Committee, the ethical precepts recommended by the National Association of Postgraduate Studies and Research in Education (ANPED, 2019) were met, especially regarding the self-declaration of ethical principles (Mainardes; Carvalho, 2019).

The research was presented to the school principal and teachers who would assist in the data collection process. After obtaining authorization from the school management and teaching staff involved, the Informed Consent Form (ICF) was sent to the parents and/or guardians of all students, in all classes in the first year of high school at the school. The ICF explained in detail the general objectives of the research, what the students would do, the possible risks and benefits, highlighted the guarantee of the physical and moral integrity of the participants, making it clear that it was not a school activity and that, therefore, participation of students was voluntary and not mandatory. The students handed in the signed ICF document.

The research was also detailed to students prior to the data collection process. Details about the justification, objectives, methods, possible risks and benefits of the research were clarified and then the students' assent was collected. All students agreed to participate.

Right at the beginning of the data processing, each student's name was replaced by a general number. Each pair also received a code. This way, the identity of the participants was preserved throughout the data analysis process.

Participants answered to the questionnaire that sought to identify their epistemological beliefs. The instrument, presented in Figure 1, is composed of three essay questions that ask students about specific aspects of scientific experiments. The questions used in this questionnaire were inspired by previous research instruments (Carey *et al.*, 1989; Lin, 2018, Smith; Wenk, 2006).

FIGURE 1: Questionnaire applied in the research.

Name:____Class:______________

1) What do you understand by a scientific experiment?

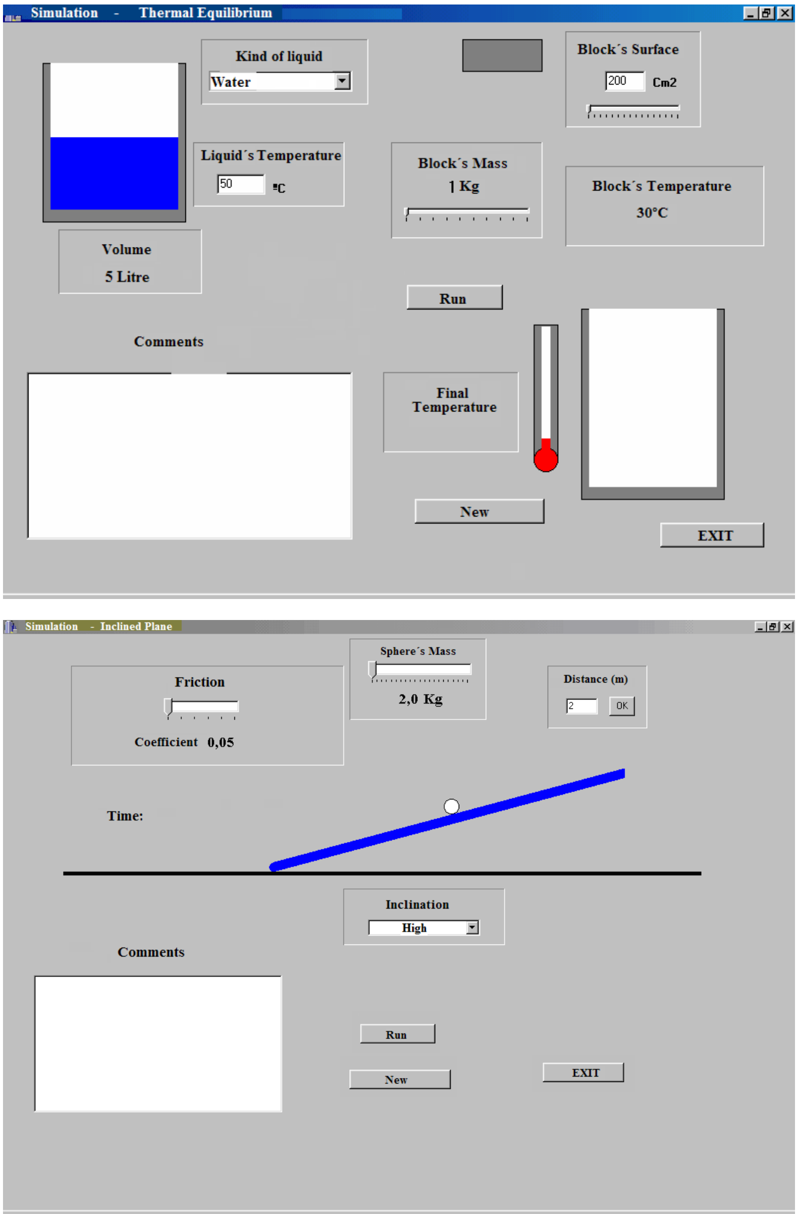
2) When can we consider a scientific experiment to be a good experiment?

3) Scientists perform experiments. What are their goals when carrying out an experiment?

Source: Authors.

Then, participants carried out investigative activities through computer simulations. With a user-friendly interface, the simulations were easily understood and used by research participants. The main screens of each of them are shown in Figure 2. The students had weekly IT classes, and therefore, using the computer itself did not pose any specific difficulties for them.

FIGURE 2: Main simulation screens.



Source: Authors.

Simulations were developed that addressed two themes (thermology/thermal equilibrium and accelerated motion/inclined plane), but with similar experimental configurations. It is important to highlight hat these contents had already been studied by the students, according to the school's regular curriculum, without any connection with the research under analysis.

The objective of each investigation was to establish which of the independent variables exerted an influence on a given dependent variable[4]. Among the independent variables, there were causal ones (which influence the dependent variable) and one non-causal one (which has no influence on the dependent variable). Table 1 describes the main characteristics of the investigative activities carried out.

TABLE 1: Characteristics of investigative activities.

Investigation	Objective	Factors/Variables	Types of variables
Thermal Equilibrium Problem (TEP)	To determine which factors influence the final temperature of the system	Surface area of the block Mass of the block Temperature of the liquid Type of liquid	Discrete (20 levels) Discrete (10 levels) Continuous Nominal (3 levels)
Inclined plane problem (IPP)	To determine which factors influence the time it takes for the spheres to travel down the ramp	Friction Distance Inclination Mass of the sphere	Discrete (6 levels) Continuous Nominal (3 levels) Discrete (20 levels)

Source: Authors

Data collection took place at the beginning of the second academic semester, during normal Physics class hours, which were provided by teachers to carry out the research. After answering individually to the questionnaire to identify epistemological beliefs, the students were taken by the teacher to the computer room. Students were instructed to sit in pairs, with freedom to choose their partner. Before the students began each

[4] To communicate with students, the objectives of the activities were treated in a more colloquial and easy-to-understand way for them. The objectives communicated to students are in Table 1.

investigation, one of the research authors explained how the simulation worked and clarified any occasional questions.

During the activity, the pairs filled in the values of the independent variables, justifying, in an appropriate area, the determined values. Then, at the click of a button, the result was provided, with a brief animation, and a comment was requested on the result obtained. At the end of the comment, each duo had the option of continuing with the investigation or exiting the program. Upon leaving, all information was recorded and stored in a file with the extension '.txt', which remained available for analysis. These files, with the report of the investigation, were a source of fundamental data in this study. Figure 3 displays an example of these reports and how the information was filed. It is possible to verify that all the data provided for the variables, in addition to the justifications, predictions and comments on the results were saved, allowing the analysis and evaluation of the experimental performance and the reasoning of the pairs during the execution of the activity. Through records, we can therefore know: (i) the number of experiments carried out; (ii) the experimental modifications made between each data collection and the reason for carrying out each experiment; (iii) whether the pairs adopted appropriate variable control strategies; (iv) which variables received more or less attention from the pairs during the investigation.

Each class carried out the research activities in two lessons of 100 minutes each, one for each investigation over the course of a week. The order of the investigation topic varied from class to class. Therefore, students from certain classes carried out TEP activities in the first class and IPP activities in the other, with the same partners. For other classes, the opposite occurred. In the present work, only data relating to the first activity carried out by the pairs is considered.

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FIGURE 3: Example of the report of an investigation**.**

Class 6 – Student 149 and student 154 – Thermal Equilibrium Problem

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Experiment: 1
Prediction:
The water will give up heat to the block until there is thermal balance.

Liquid Temperature: 50 °C
Type of Liquid: Oil
Quantity of Iron: 1kg
Area of the Iron: 200 cm^2

Final Temperature: 49.6 °C

Comment:
It was as expected. The temperature of the water decreased and the temperature of the block increased because heat was exchanged.

Experiment: 2
Prediction:
The area of the block does not influence because the mass remained constant and there will be the same heat exchange.

Liquid Temperature: 50 °C
Type of Liquid: Oil
Quantity of Iron:1 kg
Area of the Iron: 300 cm^2

Final Temperature: 49.6 °C

Comment:
It was as expected. The area of the block does not influence.

Experiment: 3
Prediction:
The mass will influence since the water will need to give up more heat to the block.

Liquid Temperature: 50 °C
Type of Liquid: Oil
Quantity of Iron: 3 kg
Area of the Iron: 200 cm^2

Final Temperature: 48.7 °C

Comment: It was as expected. Since the mass influences the final temperature of the mixture.

Experiment: 4
Prediction:
The type of liquid influences because each liquid has its specific heat.

Liquid Temperature: 50 °C
Type of Liquid: Water
Quantity of Iron: 1 kg
Area of the Iron: 200 cm^2

Final Temperature: 49.3 °C

Comment:
It was as expected.

Experiment: 5
Prediction:
The temperature of the liquid influences since it provides the necessary heat for the block and in the end the temperature of the system increases.

Liquid Temperature: 80 °C
Type of Liquid: Water
Quantity of Iron: 1kg
Area of the Iron: 200 cm^2

Final Temperature: 78.2 °C

Comment:
It was as expected. We finished the activity.

Source: Authors.

Data analysis and discussion

To evaluate the participants' epistemological beliefs, the students' answers in the questionnaire were evaluated together and categorized into two categories, according to four criteria, put together from contributions such as those by Carey and Smith (1993) and Smith and Wenk (2006): (i) general characteristics of the answers; (ii) the role attributed to scientific experimentation; (iii) the relationship between theory and experimentation; (iv) the objective of science. Table 2 presents the criteria, describing them according to the categories.

Students’ answers were categorized independently by the two authors. The percentage of agreement was 91.8%, with the 15 cases in which there was disagreement in categorization being verified after conversation and consensus between the authors. In Table 3, there are examples of answers from 6 participants categorized according to the established criteria.

TABLE 2: Criteria and categories used in the analysis.

Criteria	Categories	
	Naive	Adequate
General characteristics of the answers	The answers are poorly elaborated and vague.	The answers are more organized, better elaborated.
Scientific experimentation	Experimentation is seen only as a way of proving or confirming what the scientist already knows or has discovered.	Experimentation is seen as the way in which scientists test their ideas or hypotheses.
Theory x experimentation relation	Does not demonstrate concern about the role of scientists' ideas in the scientific process.	Recognizes and makes an explicit distinction between ideas and experimentation, considering scientists' theory important for experimentation.
Objective of science	Science is seen as a means of solving problems, making discoveries, learning new things and/or discovering how something works.	Science is seen as a means of explaining natural phenomena, evaluating and testing ideas, hypotheses and theories.

Source: Authors.

Of the total number of participants, 122 (66%) had their answers categorized as naive and 62 (34%) as adequate. This result corroborates results from previous research that state that a large proportion of Basic Education students, in several countries, have naive and fragmented beliefs about the NOS, the process of production and development of scientific knowledge (Khishfe, 2022; Lederman; Lederman, 2014).

Although individual perceptions may vary, it was possible to identify a pattern based on inductivist-positivist, atheoretical, empiricist and/or objectivist views, in relation to the answers categorized as naive, also evidenced by the high percentage of agreement in the evaluation of the answers (indicating ease categorization). For them, the essence of scientific activity is experimentation, disregarding the role of existing hypotheses and theories, which are fundamental to guide investigations. They believe in a restricted view of the scientific method, as being a set of rigid steps that must be followed and that undoubtedly lead to the desired result. Science is seen as an immutable, infallible and exact body of knowledge, obtained incontrovertibly through experimentation.

TABLE 3: Examples of participants' answers.

Questions	Answers	
	Naive	Adequate
1	A1 – Practical activity that proves hypotheses (which justify the behavior of natural, physical or chemical phenomena). A2- A scientific experiment, for me, is when they try to prove/discover something through experiments, mixtures, something in the laboratory. A3 – An activity for scientists to learn more about a phenomenon and its characteristics.	A4 – An experiment to test a theory or hypothesis. A5 – It is an experiment carried out with the aim of testing a hypothesis or seeking to explain something that does not yet have an answer. A6 – It is a controlled study that is carried out to draw conclusions about a phenomenon. To see if what scientists are thinking is right or wrong.
2	A1 – When you can clearly prove the hypotheses created about the "subject" it involves. A2 – When it works. When it shows us something that helps us reach the desired goal. When it shows us something constructive. A3 -When it meets the objectives already established before the experience, without major difficulties.	A4 - When you can determine whether the hypothesis is correct or wrong. A5 – When it helps scientists explain the phenomenon and decide which theory or idea is right. A6 – When errors are minimized, procedures are carried out carefully. Thus, the scientist can analyze the experiment data, understand the phenomenon and check whether his thinking is correct.
3	A1 – To create scientific laws and understand the facts. A2- To discover new things (disease cures, new types of energy...) and learn about phenomena. A3 -To prove the ideas already formulated by them.	A4 – To Test hypotheses and help formulate theories. A5 – The objective is to test an idea or hypothesis they have about the phenomenon. A6- The objective is to check whether a hypothesis is valid or not. If it is not valid, scientists can modify their theories and carry out new experiments.

Source: Authors.

In search of answers to the research questions, aspects of the students' performance during the investigation and their respective epistemological beliefs were compared. To do so, we identified the pairs in which both students had their answers classified in the the same category. In other words, the two partners had similar epistemological beliefs. 46 pairs were identified.

Initially, we investigated whether there were differences in the number of experiments carried out, with the results being presented in the second column of Table 4.

TABLE 4: Epistemological beliefs and the number of experiments carried out.

Categories	Number of pairs	Average number of experiments performed	Percentage of valid and conclusive tests
Naive	36	5,50	63%
Adequate	10	5,40	85%
General	46	5,48	68%

Source: Authors.

The average of the two groups was quite similar. The Kruskal-Wallis test was performed, which is a non-parametric test used to compare two or more samples that are independent of each other. The test informs whether there is a significant difference between the groups and its application uses numerical values put into ranks and grouped into a single set of data. Through the average of the positions, a comparison between the groups is made. The result, $H(1)=0.041$, $p=0.840$, indicates that there is no significant difference between the groups in terms of the number of experiments carried out.

Among the skills and procedures that characterize the scientific investigation process, the ability to carry out valid and conclusive experimental tests stands out. We analyze the possible relationship between epistemological beliefs and students' ability to set up these types of experimental tests. A valid and conclusive test is one that takes the variables proposed in a problem situation and handles them in a similar way to what the literature calls a variable control strategy. The test is valid if the variable whose effect is to be determined is taken as an independent variable. The test is conclusive if only this variable changes between two or more experimental repetitions, with all other variables remaining unaltered (Schwichow *et al.*, 2016). The third column of Table 4 presents the average percentages of valid and conclusive tests according to the categories.

It can be noticed that there is a difference between the averages of adequate and consistent experiments according to the categories analyzed. Pairs formed by students with more sophisticated epistemological beliefs performed, on average, more adequate and consistent tests. The result of the Kruskal-Wallis test, $H(1)=2.609$, $p=0.106$ indicates that the result is marginally significant.

To try to establish a relationship between the students' epistemological beliefs and their performance during the activity, the quality of the research carried out by each pair was classified according to the categories proposed by Nascimento and Gomes (2018). The categories, defined in Table 5, concern, above all, the exploration of the experimental field and the use of valid and conclusive tests.

Also considering the same 46 pairs, the relationship between the quality of the research carried out and epistemological beliefs was analyzed. The results are presented in Table 6.

TABLE 5: Categorization of experimental performance.

Performance	Description
Very good	When the pair performed at least one valid and conclusive experimental test for all independent variables.
Good	When the pair performed at least one valid and conclusive experimental test for at least 50% of the independent variables.
Poor	When the pair performed most of the experimental tests inconsistently and explored the influence of a few independent variables.

Source: Authors.

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It can be observed that 70% of the pairs formed by students with more appropriate epistemological beliefs had their experimental performance categorized as Very Good, with no pair formed by students with more appropriate conceptions having their performance in the activity categorized as Poor. In turn, regarding to the pairs formed by students with more naive epistemological conceptions, around a third of them had their experimental performance classified as Very Good, a third of the pairs were assessed as Good and a third had a Poor performance. To verify whether the differences presented are statistically significant, the chi-square test was performed. One of the uses of the chi-square test is to verify the independence or the existence of some relationship between two categorical variables in double-entry tables. The result found was $\chi 2(2)=6.529$, $p=0.038$, which highlights the statistical significance of the result obtained.

TABLE 6: Relationship between experimental performance and epistemological beliefs.

Performance	Epistemological beliefs		Total
	Naive	Adequate	
Poor	12	0	12
Good	13	3	16
Very Good	11	7	18
Total	36	10	46

Source: Authors.

Therefore, given the results presented, there is evidence of the relationship between students' performance in carrying out investigative activities and their epistemological beliefs. The results presented corroborate previous studies that also suggests this relationship (Driver *et al.*, 1996; Millar *et al.*, 1994).

Final considerations

The objective of this study was to explore the relationship between epistemological beliefs and the experimental performance of students during investigative activities. Answering the research question, the results indicate a relationship between epistemological beliefs and students' experimental performance. Pairs composed of students with more appropriate epistemological beliefs tended to present more sophisticated variable control and experimentation strategies, thus presenting better performance in investigations. This was evidenced by the greater number of valid and conclusive tests carried out and by presenting, in percentage terms, a superior experimental performance.

The results presented endorse previous research on the existence of a pattern of naive, fragmented, inductivist and atheoretical beliefs that most Basic Education students have about the process of production and construction of scientific knowledge, at all levels of education (Deng *et al.*, 2011; Van Griethuijsen *et al.*, 2015).

Science teaching can benefit greatly from giving attention to the interaction between students' epistemological conceptions, attitudes, and learning strategies. While practical activities can provide the opportunity for students to play a central role in the knowledge generation process, they also provide the teacher with the opportunity to address various epistemological questions about the role of evidence, the role and development of scientific theories, and the main characteristics of scientific knowledge. Furthermore, throughout the activities, students' epistemological considerations must be taken into account and epistemological reflections must be an integral part of the activities developed and must be incorporated for long periods.

A limitation of the research carried out is the way in which the participants' epistemological beliefs were identified, through a questionnaire, with general and open questions. There are criticisms regarding it. Studies indicates that students' epistemological beliefs are sensitive to research

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instruments and dependent on the context of the questions applied (Allchin, 2011; Matthews, 2012; Metz, 2011). This issue poses a challenge for the area of science education, because as Lee and collaborators (2021) state, even with validated instruments, researchers conclude that epistemological beliefs are plastic, sensitive to teaching opportunities and vary according to the context.

The research carried out suggests that carrying out investigative activities can create conditions and opportunities for students to obtain a better understanding of the epistemological foundations of science and the process of building scientific knowledge, as long as this is explicitly and properly addressed by the teacher (Lederman; Abd-El-Khalick; Lederman, 2020; Lederman; Lederman, 2014).

However, investigative activities are not necessarily sufficient for the development of more sophisticated epistemological beliefs, since, even if students effectively engage in these activities and take advantage of their benefits to build their conceptual and procedural knowledge, they may still maintain a naive view on aspects of the NOS and its epistemology.

> The way through which activities are developed can have direct consequences on students' epistemological conceptions and on the potential that this learning environment has to develop such conceptions (Gomes, 2009, p. 269).

New questions for future research can also be formulated: how do the research activities carried out by students shape their epistemological beliefs? Which stages of the investigation process or which skills related to the scientific investigation process may be influenced by epistemological beliefs?

If there is ambition to develop knowledge and skills related to the process of experimentation and more sophisticated epistemological beliefs on the part of students, it becomes necessary to develop teaching strategies and continually implement appropriate ways of evaluating these objectives by researchers and teachers.

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