The understanding of the nature of science among Spanish pre-service primary teachers

Comprensión del profesorado español de enseñanza primaria en formación sobre la naturaleza de la ciencia

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Abstract

Nowadays, the study of the nature of science (NOS) and its implications for science education is considered to be an important aspect of teachers training courses. Understanding the nature of science is a fundamental prerequisite in order for the teacher to be able to adequately direct the learning process. The purpose of this study is to assess spanish, pre-service, primary teachers' knowledge of the NOS. Three characteristics of NOS were identified as most common from the research into NOS within Science Education and a questionnaire based on these characteristics was designed to evaluate students' understanding of NOS. The questionnaire was completed by students on the second year of the degree in Primary Science Teaching. The results provide evidence that some misconceptions about the NOS are common among pre-service primary science teachers in different countries. The majority of students do not recognize that observation depends on theory and neither that scientific knowledge is conceptualised within a socio-cultural framework. Implications for primary science teacher education are discussed.

Key words: *nature of science, teachers' conceptions, science teacher training.*

Resumen

Existe un consenso general entre los educadores respecto a que, una adecuada comprensión de la naturaleza del conocimiento científico es un requisito necesario en la formación del profesorado de ciencias. Este trabajo trata de indagar sobre las concepciones del profesorado de ciencias de primaria en formación, respecto a la epistemología científica. Para ello, se ha diseñado un cuestionario abierto para que los profesores en formación expliquen sus opiniones sobre diferentes aspectos de la naturaleza de la ciencia. Los resultados obtenidos confirman que determinadas concepciones alternativas sobre la naturaleza de la ciencia son comunes a profesores de diferentes países. La mayoría del profesorado manifiesta una concepción empírico-falsacionista. Se indican algunas implicaciones para la formación del profesorado de ciencias.

Palabras clave: *naturaleza de la ciencia, concepciones del profesorado, formación del profesorado de ciencias.*

INTRODUCTION

In spite of some known differences in contemporary epistemology of scientific activity, the philosophers of science, in particular, KUHN, LAKATOS, LAUDAN & TOULMIN have a coherent vision of the nature scientific investigation that has important implications for science education (CHALMERS, 1982; BELL, *et al.*, 2001; HODSON, 1992). A significant bibliography of publications about the use of the history of science in science education is presented in *Science Teaching: The Role of History and Philosophy of Science* (MATTHEWS, 1994). This book is a multidimensional report of the debate on the potential of a rapprochement between history, philosophy and science education. It highlights the problems within science education which may be alleviated by beneficial contributions from history and the philosophy of science.

Nowadays, together with knowledge of the contents of the discipline (knowledge about what the students have to learn) and pedagogical (knowledge about how to deliver the information to the students) a general consensus exists among educators with respect to the pertinence of possessing knowledge of the contemporary conceptions of the Nature of Science (NOS) (AAAS 1990, NRC 1996).

Much research has shown that the image students have of science depends in large part on that of the teachers, who usually have a distorted image of scientific activity themselves (LEDERMAN, 1992; FERNÁNDEZ *et al.*, 2002). It therefore seems logical to affirm that ensuring a good, up-to-date, understanding of the nature of scientific knowledge is a necessary part of the preparation of science teachers (ABD-EL-KHALIC & LEDERMAN, 2000; ABD-EL-KHALIC, 2001; BARTOLOMEW, OSBORNE & RATCLIFFE 2004; MELLADO, 1998). However, in Spain the treatment of questions related to the NOS does not often appear in training courses for prospective teachers of science, in primary or secondary education.

The study which is set out here, constitutes one stage of a project whose goal is to develop an approach that intentionally draws the attention of pre-service teachers to relevant aspects of NOS through specific questioning, guided reflection about situations and guided investigations designed to improve the conceptions of pre-service teachers of NOS. The project will be undertaken in the context of a three-year degree programme in Primary Science teacher training, at the University of the Basque Country (Spain).

This first stage is focused on the assessment of student teachers' understanding of NOS during the last month of the spring term, in the second year of a science education course. The research question of the study is the following: What are Spanish pre-service Primary teachers' ideas of NOS? We subdivided the question into three complementary parts: What students think about 1) The objectives of scientific activity; 2) The nature of scientific methodology; 3) The development of scientific knowledge.

EXPERIMENTAL DESIGN

A possible starting point for obtaining better information about the conceptions held by prospective teachers about the NOS is to define the knowledge that they should have into it. The research into NOS in the teaching of science has reached a wide consensus in pointing out the following aspects of scientific activity that should be taught and known by teachers (ABD-EL-KHALICK, 2001; BENTLEY & GARRISON, 1991; CHALMERS, 1982; CLEMINSON, 1990; COLLINS *et al.*, 2003; DUSCHL, 1990; FERNÁNDEZ *et al.*, 2002; HODSON, 1992; KOBALLA *et al.*, 2005; LEACH & LEWIS 2002, LEDERMAN *et al.*, 2001; MASON, 2002; MCCOMAS, 1998; OSBORNE *et al.*, 2003; VÁZQUEZ *et al.*, 2006). A summary of these common aspects is presented in Table 1.

Table 1

Summary of the general consensus of the characteristics of the NOS

Aspect of the Nature of Science	Characteristics
a. The role of science	a.1) The role of science is to provide *explanations for natural phenomena*, science is considered as a discipline to address questions about the natural world that a.2) uses a *proper methodology, and empirical evidence* plays a important role that separates science from other 'ways of knowing'. Moreover a.3) science is involved in the socio-cultural context and it is influenced by social and cultural values, personal *subjectivity* and research-programs inference. a.4) Science is an activity that involves *creativity and imagination*, as other human activities, and some scientific ideas are enormous intellectual achievements.

b. Methodology of science	b.1) science uses empirical evidence to test ideas, but scientific knowledge does not emerge simply from the data, but through a process of interpretation and theory building. *There is a clear distinction between experimental data and explanations*. b.2) scientists develop *hypotheses* and predictions about natural phenomena which are then tested empirically. b.3) science uses a *range of methods* and approaches and there is no one scientific method or approach.
c. Development of science knowledge	c.1) the work of a scientist involves a continual and cyclical process of asking questions and seeking answers which then lead; to new questions. So, scientific knowledge is *tentative* (subject to changes). c.2) Current scientific knowledge is the best we have, but may be subject to change in the future given *new interpretation of old evidence;* because of problems with predictions or universality; or *new evidence*.

We designed an open-ended questionnaire to assess student teachers' understanding of NOS. The questionnaire included 8 questions to probe respondents' views of the aforementioned aspects of NOS. The question format requires student to use their own conceptions to explain rather than to choose from among different theories. The choice of this format was based on the fact that students are supposed to know the scientific theory sufficiently well to answer the question.

The first four questions in the questionnaire had previously been used by other researchers and had been shown to be effective in investigating students' conceptions about NOS (Abd-El-Khalic 1998, 2001; Lederman *et al.*, 2001). We also designed another four questions to address the objective of the second and third parts of the research question. Questions 5 and 6 are related to the second part of the research question, as are questions 3 and 4, but here we want to ascertain, in concrete terms, the students' opinions of the relations between the theory and the experiments. Questions 7 and 8 addressed the third part of the research question about the scientific development and the factors that influenced it. Inquiry into each part of the research question was made by more than one question. Cross-checking the same issue in different settings also facilitates the characterisation of the students' knowledge and reasoning (Viennot, 1996). The questions are included in the Annexe.

The questions were analysed by two colleagues who have expertise in science education and science-teacher education. They were asked to comment on the adequacy of the questions with regard to both the objectives of the study and the subject covered. They filled out the questionnaire and made suggestions that were taken into account in writing the final version of questionnaire.

Also, fifteen pre-service teachers, not involved in the present study, were interviewed to answer the questions. This confirmed that, in general, students did not have a problem understanding the meaning of questions. The interviews were particularly useful in order to clarify the possible answers to some questions. For example, in question 6 the word 'temperature' is usually taught as a 'real phenomenon' in the sense that it is a measure of a physical characteristic of matter and, this is the kind of answer that we hoped to find for the question. Nonetheless, one could argue that 'temperature' is a concept that is based on a theory of matter and could be measured on a number of scales and can thus be thought of as a 'theoretical idea'. However, none of students interviewed answered in this sense. In the same way, in item 7, one way of 'quantifying' scientific development is by considering the volume of scientific knowledge produced, but one can graph also scientific development considering the accuracy of this knowledge, or the development of methodology and instrumentation. In all students' explanations of question 7, the graphs considered the volume of knowledge and technological applications produced in a period of time. So, this is the interpretation that we consider in the analysis of answers in the questionnaire.

The questionnaire was completed under examination conditions, supervised by one of the authors. The sample is made up of students studying a science education course, in the second year of the Degree in Primary Science Teaching. 42 student teachers answered the questions and the other part of the sample. Students took about 45 minutes to complete the first part and 15 minutes for the second part of the questionnaire.

Next, we describe the process followed in order to analyze the answers. We derived a set of categories for each question on the basis of the established goals in chart 1 and the exhaustive analysis of the answers of questionnaire, by a member of the research team. The students' answers were classified in agreement with the categories defined, then we held a training session in which we examined 10% of the sample. Next, the members of the research team went on to analyze the remaining questionnaires independently. The level of agreement between the reviewers on classifying the answers was more than 85% for each question. In the cases of disagreement, the definitive categorization was made by means of discussion and consensus between the three reviewers. Once the analysis was over, we found that the tendencies of frequencies of the categories of answer are convergent for those questions with the same objective and similar difficulty.

RESULTS

In this section frequencies per aspect of NOS evaluated are given for each question. The presentation of results is organized into three sections. First, student teachers' conceptions about the role of science are presented. Second, results of the student teachers' conceptions about scientific methodology are presented, as well as some comparisons between different questions. Finally, student teachers' conceptions about scientific development are described.

What role do student teachers attribute to scientific activity?

Questions 1 and 2 were designed with the objective that student teachers explain the role that science plays in our society; what are, in their opinion, its objectives and characteristics. The frequency and percentage of the different types of replies given by student teachers are indicated in Table 2.

Table 2

Frequency and percentages of aspects of the NOS highlighted in questions 1 and 2

Questions	Provides explanations of natural phenomena	Uses empirical evidence and specific methodology	Considers social context	Unclassifiable	No answer
Q1	30 (71.5%)	7 (17.0%)	8 (19.0%)	12 (29.0%)	1 (2%)
Q2	14 (33.0%)	17 (40.0%)	-	13 (31.0%)	-

The majority of the replies to question 1 (71.5%) mention that science tries to provide explanations to phenomena or natural problems. For example:

- To analyse in a different way the living forms and phenomena that appear in Nature.
- It is the investigation into an unknown fact which is carried out by means of diverse techniques.

Within this group 8 student teachers point out explicitly the social context in which the scientific activity is developed and another 7 point out the specific character of the scientific methodology in responding to natural phenomena, indicating that such investigation has its own characteristics. Here are some examples of this kind of response:

- Discipline that carries out studies in order to understand more about the world around us and what can be done to improve and exploit it to advantage.
- It is a discipline which by means of the observation of natural phenomena elaborates hypotheses, carries out experiments to prove such hypotheses and if found to be true, formulate laws.
- It is the one that analyses in a scientific way (with hypotheses, tests and generalising the results obtained) the phenomena, connections and so on that happen in the world.

Almost 30% of the replies provide unconnected or even undecipherable explanations, from which we can conclude that there has been a lack of prior reflection about the objectives and the role played by science. Here is an example:

Experiments carried out to analyse the world and society

The results of question 2 concur with those of the previous question. The student teachers again point out that scientific knowledge is reached by means of empirical evidence (40%) and attribute to it values of "objectivity" and "exactitude". Here are some examples:

- The scientific disciplines require formulae, must follow steps and are always based on the demonstrable.
- The scientific disciplines are more objective, based on the material itself; the others are more subjective and social in which the person is an important part.

Likewise, about a third of the replies centre their explanations on the objective of the nature scientific disciplines. In their opinion these study the natural phenomena, are related to mathematics and are "practical" (i.e. involve experiments), whereas the other disciplines have subjects related to the "human being" as their objective and are more subjective. Some examples of this category are:

- The scientific disciplines study the phenomena of nature; the others study human beings and their behaviour.
- The first ones are nature sciences, which explain the environment, the others investigate topics related to society.
- The first are directed towards the field of numbers; the others are closer to the field of arts..
- The first ones are analysed and investigated through numbers, the others, on the other hand, through thought.

There are a significant number of replies (one third) that answer in an incoherent way, indicating once again, that the student teachers have not given any reflection to these questions.

Important aspects of the epistemology of contemporary science such as creativity and imagination that are necessary to develop new theories and explanations are not mentioned by any student teachers. In the same way only 8 answers to question 1 speak about the socio-cultural influences on scientific knowledge and none mentions the personal subjectivity and influence of research programmes in the work of scientists. On the other hand, many answers to the second question mention the "objectivity" and "exactitude" of the scientific disciplines in contrast to the other disciplines, such as philosophy or psychology.

How do the student teachers explain scientific methodology?

Questions 3 and 4 were designed for the student teachers to explain the role of the experiment within scientific activity. In question 3 they are faced with a direct question where they define the characteristics of an experiment and in question 4 they are asked about the role played by experiments in the development of scientific investigation.

Another aspect highlighted by contemporary scientific epistemology is the clear distinction between empirical evidence and theoretical explanation. Questions 5 and 6 are intended to test what student teachers think about the role played by theory in scientific knowledge. Question 5 asks directly about the reliability of scientific theories and question 6 asks student teachers about the difference between empirical evidence and explanatory theories.

In Table 3 the different aspects of the NOS found in the replies to questions 3 and 4 are set out.

Table 3

Frequency and percentages of aspects of the NOS pointed out in questions 3 and 4

Questions	Empirical proof	Test hypothesis	Discovery of new theories	Unclassifiable	No answer
Q 3	21 (50.0%)	10 (24.0%)	5 (12.0%)	8 (19.0%)	1 (2.3%)
Q 4	19 (45.2%)	5 (12.0%)	14 (33.3%)	5 (12.0%)	3 (6.9%)

In question 3.50% of answers define the experiment as a test for empirically checking a statement or theory, but fail to specify how the theory to be tested has emerged. For example:

- It is an action for checking if something found, made,… works.
- It is valuable for checking things and is related to proof.

More than a third of the answers explicitly indicate that it is necessary to first develop a hypothesis that will be checked later by means of experiments. Here is an example of this kind of answer:

- Method of checking if the hypotheses put forward are true or false.
- Action taken after a hypothesis has been proposed to check if it is right or not.

However, none of the answers include the definition of experiment as the reproduction of a natural phenomena, in controlled conditions, that allows the measurement of variables. Nor do they indicate explicitly that it is one part of a more global and complex investigation.

The results of question 4 show that practically all student teachers consider that scientific knowledge needs experiments for its development. Only 5 student teachers consider that experiments are not necessary in all research investigations, but fail to provide justification. In agreement with the results of question 3, a large number of explanations (57,2%) discuss the importance of experiment as empirical proof of theories, without indicating any other type of validation of the theories such as their predictability, universality and coherence with the theoretical framework. Here is an example:

- Experiments are necessary because one of the pillars on which science is based is that its theories must practically demonstratable, otherwise they would not be scientific knowledge.
- Yes, they are necessary because if you don't experiment you will not be sure if the theory is valid or not.

A third of the explanations consider that it is by means of experimentation that explanations or theories are generated, in a clear empirical-inductivist conception of science. An example of this kind of answer is as follows:

- Yes, because research is carried out through experiments.

Question 5 was answered by student teachers and almost 75% confer a very high degree of certainty to the theory of the electrons, only 4 answers indicate a medium level of certainty and none attribute it with a low degree of certainty. Six student teachers give no answer. The results are shown in Table 4.

Table 4

Frequency and percentages of aspects of the NOS pointed out in question 5

Type of answer	Students (N=36) (percentage)
Certainty very high	26 (72.2%)
Certainty medium/ regular	4 (11.0%)
Certainty low	0
Because the theory is tested by experiments	26 (72.2%)
Other justifications	2 (5.5%)
No answer	6 (16.5%)

Practically all the justifications of this high grade of confidence in the scientific theory presented refer to the experiments that demonstrate the theory, as well as the technological aspects that allow the electrons to be detected. In the explanations no mention is made of the difference between experimental facts and the theoretical concepts (electron) devised to explain them. To ascertain student teacher opinion about this aspect of the scientific methodology question 6 was answered by the same sample of student teachers.

In question 6, more than three quarters of the student teachers (78%) fail to respond correctly. The most frequent errors occur when classifying the magnitudes volume (N=5) and pressure (N=7) as ideas from the theory. This is concordant with the type of justifications which appear in their explanations and that have been classified in Table 5.

The great majority of the justifications (78%) indicate that natural phenomena can be observed, measured, checked by means of suitable tools, whilst theoretical explanations cannot. These justifications seem to have a naïve, highly realistic component, since when it comes to making the classification, for example, aspects such as "pressure" or "volume" enter into the section of theoretical ideas. Only 7 student teachers express the idea that theoretical explanations are not real, do not occur in reality that we imagine them and they are explanations of scientists which are in accordance with observed phenomena. The results are consistent with those of the previous question, in which it was shown that very few student teachers knew how to clearly distinguish between experimental facts and theories.

Table 5

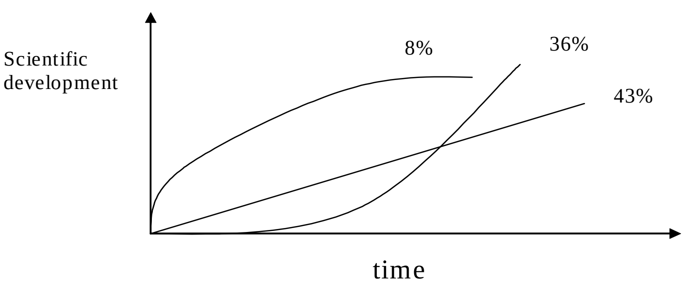
Frequency and percentages of aspects of the NOS highlighted in question 6

Type of answer	Students (N=36) (percentage)
A. Correct classification in which a distinction is made between empirical evidence and theoretical explanation	7 (19%)
B. Incorrect classification in which there is no distinction between empirical evidence and theoretical explanation	28 (78%)
No justification	1 (2.7%)

How do student teachers understand the development of scientific knowledge?

Questions 7 y 8 were designed with the objective of ascertaining what student teachers think about the evolution of scientific thought. Question 7 asks directly about the development of scientific knowledge which must be dealt with by means of a diagram and an explanation and question 8 inquires about the factors that have cause this evolution.

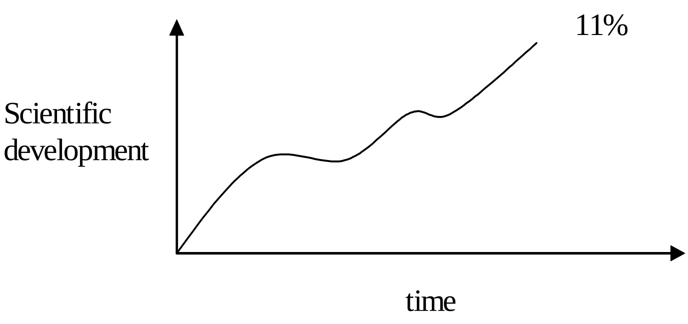
In question 7 the great majority of answers (87.0%) indicate a continual evolution of scientific knowledge and it is expressed by means of Graph 1.



Graph 1. Growing evolution of scientific knowledge

18 (43%) of the answers indicate a lineal growth, 15 (36%) express an increasing exponential growth and 3 answers indicate an inverse exponential growth. The latter justify their answers indicating that now very little remains to be invented. The justifications of the remainder are based on the advance in technology which is more and more rapid and allows the detection of these phenomena.

4 student teachers fail to answer and only 2 answer correctly, drawing a graph with advances, halts and regressions (see graph 2). Both students explain that scientific knowledge has had periods of nil growth and others of lesser acceleration.



Graph 2. Evolution of scientific knowledge

The results from question 8 have been grouped in three different factors and are shown in Table 6.

Table 6

Frequency and percentages in question 8

Type of answer	Students (N=42) percentage
Technological factors	16 (38%)
Socio-cultural Factors	14 (33%)
Personal factors	6 (14,2%)
Other factors	7 (16,6%)
No answer	9 (21%)

Almost 40% of the answers (N=16) highlight new technologies as the main factor responsible for the evolution of scientific knowledge: as they allow more data to be obtained: Here is an example of this type

- The new technologies that continue to bring and facilitate greater discoveries.
- New technologies and money.

As opposed to the answers in the previous sections, in which socio-cultural factors are not considered, in this question one third of the answers consider the socio-cultural factors as being responsible for the changes in science.

- Money, life conditions and human intelligence.
- Its main purpose has been to satisfy the needs of mankind, to make human life more comfortable.

Although both factors intervene in the processes of change, in student teacher explanations a multifactor overlap of the causes of change is not considered. Internal factors in the dynamic of science itself such as the unsatisfactory nature of the explanations with regard to the known facts and the lack of coherence in the body of knowledge are not included.

The majority of the explanations cite the drivers of change as being factors external to the process of scientific research and investigation (socio-cultural) or, to advances in technology that are considered to be separate from that of science. However, nowadays the close relationship between science and technology is known, when speaking about the development of technical-science.

Only a minority of responses (N=6) consider personal values and cultural perspectives as determining factors in what scientists do and how they do it. For example, answers such as:

- The personal interest to go further, resources etc.
- The desires, projects etc. of scientists.

Another group of similar responses (N=7) consider the main change factors to be luck, war, public health problems…etc

ARGUMENTS AND IMPLICATIONS FOR TEACHER EDUCATION

The general objective of this research was to investigate the conceptions held by students, in Teacher Training, about the objectives, methodology and evolution of scientific knowledge. The experimental design was based on a questionnaire with open questions.

The results show that the majority of prospective teachers in primary education volunteer a empirical conception whereby they consider that science is a body of knowledge formed by natural phenomena and theories (71% in Q1) that they consider to be true, in the sense of being contrasted with the observable data (50% in Q3, 72% in Q5). Coherent with the above, pre-service teachers explain that the scientific facts give meaning to the theory and the observation and detection of phenomena is the most important stage of scientific methodology (90% Q4). In this conception the student fail to distinguish clearly between theories and experimental data (78% in Q6), not even mentioning different general and flexible strategies used by science to resolve problems and contrast ideas (0% in Q3 and Q4). Scientific progress is always advancing and growing and change is produced when new experimental facts emerge, mainly due to technological advances (87% in Q7 and 38% in Q8).

Convergent with the empirical conception of the majority of pre-service teachers, the results of questions Q1 and Q8 show that student teachers do not contextualise scientific knowledge in its socio-cultural framework (19% in Q1) which point out the role played by the Society in the research programmes and that of the personal subjectivity and values of the scientists (14.2% in Q8).

It is important to point out that the results obtained in the study are convergent with the results obtained for pre-service primary science teacher students in other countries (Irwing, 2000; Glasson & Bentley, 2000; Ald-El-Khalick, 2001). So, the results of this study provide~~s~~ evidence that some misconceptions about the NOS are common to different countries, among pre-service primary science teachers.

A lack of reflection exists among prospective teachers in primary education about the nature of scientific knowledge, as evidenced by the percentage of students who fail to answer and the lack of consistency in their explanations. This situation is plausible given that, in Spain, very few initial teacher training programmes in science give consideration to the Nature of Science, and in few courses do the prospective teachers have the opportunity to debate these problems.

When science teachers in training begin their studies they must learn a wide range of knowledge characterised by what is known as “understanding the material to be taught”. Within this body of knowledge the study of the nature of science knowledge and the history of science should be included: the aims of science; the processes followed by scientists in the construction of that knowledge; the problems that led to its construction; how they came to be articulated as a coherent body of knowledge, how they evolved, what the difficulties were etc.

The understanding of the above mentioned topics is a necessary condition but not sufficient on its own, that is, it does not guarantee automatically its transfer to classroom practice. In addition, it will be necessary to supply prospective teachers with didactic materials that allow them to put their new found knowledge of the NOS to effective classroom use. The development of these didactic materials will be the objective of our second study in this research.

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QUESTIONNAIRE

Q1. In your opinion, what is Science?

Q2. What are the differences between scientific disciplines (Physics, Chemistry, Biology...) and other disciplines (Psychology, Philosophy, Geography...)?

Q3. What is an experiment?

Q4. What is the role of experiments in scientific research?

Q5. Books on experimental sciences present the electric current in a simple circuit, made up by a battery and a light bulb, as a flux of electrons that the energy of the battery moves along the cable and which, on flowing through the filament in the bulb, make it glow. What is the degree of certainty scientists have when they put forward this theory? What evidences, or types of evidence, do scientists use to justify that there are electrons going through the cable and thus justify the theory?

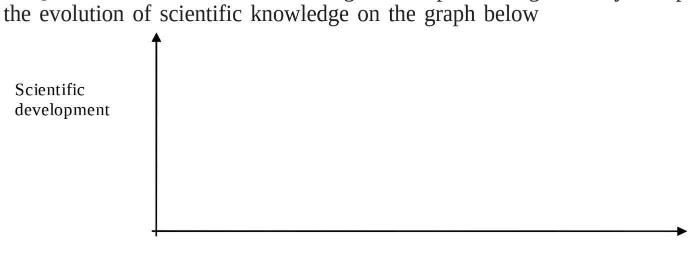
Q6. The text below explains the process of balloon heating up. Your task is to differentiate between real phenomena and the theoretical explanations described. To achieve this you must put the words, in bold in two columns: real phenomena and ideas from the theory.

> “When an inflated balloon is heated the volume of the balloon increases, because the higher temperature leads to an increase in the velocity of the gas particles and an increased separation between the gas particles. As the velocity of particles increases the frequency of collisions between them increases, as does the pressure of gas”.

Real phenomena	theoretical ideas

Explain your classification

Q7. How has scientific knowledge developed through history? Map the evolution of scientific knowledge on the graph below



Q8. What are the most important factors that cause the evolution of scientific knowledge?

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