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Exploring the Image of Science: Neural Nets and the PIKA Model

Ana Muñoz van den Eynde[1*], Belén Laspra[2] and Irene Díaz García[3]

[1]Research Unit on Scientific Culture, CIEMAT, Madrid, Spain.
[2]Institute for Social Research, University of Michigan, Ann Arbor, USA.
[3]Grupo de Investigación CTS, Universidad de Oviedo, Spain.

Authors' contributions

This work was carried out in collaboration between all authors. Author AMVDE proposed de model, designed the study, performed the statistical analysis and wrote the first draft of the manuscript. Authors BL and IDG contributed to the development of the study and revised and improved the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

In spite of the efforts devoted to understand the relationship of society with science, the results have not been satisfactory. The aim of this study is to test the PIKA model, developed to contribute to a better understanding of the perspective of citizens in the relationship of society with science. Our hypothesis is that the interaction of citizens with science generates an image that determines how they react to it. We conceive this image as a mental map, and according to contributions from neurology, we consider that it is grounded on a neural net. The PIKA model postulates that there is a section of the image of science that accounts for the interaction of Perception, Interest, Knowledge, and willingness to Act. We used Structural Equation Modelling to obtain evidence to support this model. We used data from three Spanish samples: the 2006 and 2014 editions of the Survey on Social Perception of Science and Technology by the Spanish Foundation for Science and Technology, and the answers to the PIKA Questionnaire of a sample of students from several Spanish universities. The sample of the 2006 edition of the survey of FECYT is comprised by 7.056 subjects from 18 years of age, while the 2014 edition includes 6.136 people. The sample that has

**Corresponding author: E-mail: ana.munoz@ciemat.es;*

completed the PIKA questionnaire includes 2.138 students from some Spanish universities. The results provide evidence in favour of the PIKA model in the three samples. We conclude that the image of science depicted as a neural net is useful to explain the interaction of citizens with science. Nevertheless, to achieve better understanding of this interaction we need better indicators of the factors that give shape to the citizens' image of science.

Keywords: Science and society; attitude; perception; interest; knowledge; survey.

1. INTRODUCTION

Research about the relationship of society with science has developed around two premises. First, the relationship of citizenship with science is hampered by a lack of confidence in science on part of the citizens [1,2]. Second, this difficulty is associated with some kind of deficit in the population [3,4]. Although support for science and technology is not under threat in modern societies, and no democratic publics reject globally the acquisition of new knowledge or the development of technologies that improve their daily life [5], it cannot be denied that some social controversies exist in relation to some scientific and technological developments (e.g. stem cell research [2], genetically modified organisms [6], or cloning [1]). These could be attributed to the interaction of, at least, two circumstances. First, there is the realization that some scientific and technological developments are associated with important risks and undesired effects, and this realization generates important concerns on citizens [7]. Second, the controversies seem to be related to the efforts devoted to capacitate citizens to manage a context in which science, technology, and their applications play an increasingly important role. It has been found that knowledgeable citizens tend to demand control over scientific and technological developments affecting their way of life [7].

After more than twenty years of researching effort, numerous criticisms have emerged in the field, as reflected, for example, in the the Special Issue about Public Engagement in Science published by *Public Understanding of Science* magazine in 2014. They are grounded both in the rejection of these two premises and in the finding that, in spite of the efforts devoted to understand the mechanisms involved in the relationship of society with science, the fruits harvested have been scarce. We consider that the inability to provide significant results is due to the fact that research in this field has incurred in circular thinking and in reproducing outdated models [8]. There are multiple evidences of this circularity. For example, the absence of a theoretical framework is considered a very relevant constraining factor, but it remains unformulated [9]. Questions from surveys of public perception of science are criticized, but they remain unchanged [9]. Besides, the deficit model remains in effect in spite of the rejection it generates. As Martin Bauer pointed out in the Editorial of the May 2016 issue of *Public Understanding of Science* magazine, “despite 20-plus years of polemics and positioning against the deficit concept, it seems that this concept has an unusual staying power. It tends to come back in one way or the other even in different guises” [4].

We attribute the problem of circularity to two factors. First, considering the distinction between basic and applied science, it can be said that the research of the relationship of society with science resembles applied science. It has been guided by the objective of obtaining information useful to guide the design and implementation of strategies to build a bridge between science and citizenship, and not in order to properly understand the way citizens relate with science. This strategy has generated a kind of forward flight, the tendency to make new proposals without devoting sufficient time and effort to reflection. Second, although there is wide consensus around the idea that there is not a unique scientific method, all scientists share a distinctive methodological culture [10]. We consider that the research of the relationship of citizens with science has not been sufficiently embedded in this culture.

In the culture of science, theory is crucial. Theory governs the researcher’s perception of the problem(s), determines the design of the methodology, and influences the interpretation of the results [11]. However, the lack of a theory has been identified as one of the most important weaknesses of the research of the relationship of society with science [3]. Besides, in the culture of science instruments develop a fundamental role, as it is assumed that data obtained with reliable instruments are objective [10]. The development of reliable instruments requires from a dialog between conceptualization and operationalization. But items and questionnaires have been designed irrespective any conceptual development about what is being measured and, consequently, how it should be measured [9]. In the development of a questionnaire we can use a top-down approach, from theory to observations, or a bottom-up approach, starting with the observations to obtain the theoretical construct. This last is clearly an inductive approach that requires a very good selection of the items of the questionnaire to guarantee content validity [12]. A large number of items are needed in the initial phases to make later a process of depuration to select the items that best represent the theoretical framework [13]. This also requires a refined analysis of the data obtained [12]. The design of the surveys of public perception of science lacks of both requisites [9]. The desire to understand the world by means of the analysis is another essential feature of the culture of science. However, although a description is not an explanation [10], data from public opinion surveys of science have been object almost exclusively of descriptive analyses. This can be interpreted as a proof that, in this field of research, the instruments (the surveys) have not been developed as a tool to advance the acquisition of knowledge.

Finally, we consider that the research of the relationship of society with science has forgotten that those answering the surveys are individuals. The development of the surveys has grounded on two assumptions. First, human beings are rational and offer all their answers and judgements after thinking thoroughly and in detail on them. Second, citizens have an opinion on all issues of interest to social researchers and are willing to manifest it the moment an interviewer knocks on their door. Nevertheless, there is increasing evidence that these assumptions do not properly reflect the reality of the interviewees. It has been found that the way a question is formulated conditions the cognitive processing of the information that contains [14]. There is also evidence that the context of the survey, i.e., the position of the questions into the questionnaire, influences the answers. If respondents had an opinion about the issue stored in their memory and waiting to be remembered, the context would not have any influence [15]. All these evidences are a consequence that our cognitive processing responds to the law of minimum effort. The situation of answering a survey triggers the system 1 of cognitive processing that is intuitive, fast, and operates in parallel [16].

This work puts forward a bottom-up approach, from data to theory to help in overcoming the weaknesses so far mentioned. This approach assumes that the relationship of citizens with science depends and simultaneously determines the image they have of it. It also considers that research will benefit from the identification of the factors involved in shaping the citizens' image of science by means of multivariate analyses. To achieve this goal, a first step consisted in designing and distributing a survey different from those that traditionally have addressed the public perception of science, the PIKA survey [17].

Surveys of public perception of science rely on probabilistic samples and, therefore, the design of the questionnaire is subordinated to the needs this sampling strategy generates: to ensure the response rate, the questionnaires have to be accessible and easy to answer, and both facts limit content validity [12]. In the PIKA survey, on the contrary, the sampling strategy is secondary to the questionnaire. Regarding that cognitive heuristics and biases pose important challenges to the accuracy of data gathered by surveys of public opinion [15], it is assumed that the only way to try to avoid the problems associated with cognitive processing is by a very careful design of the questions to be asked. They were formulated trying to assure that respondents answer to what is being asked. The result is a questionnaire consuming effort and time. Therefore, PIKA relied on a convenience sample of undergraduate students that were contacted through the institutional e-mail provided by their university. The e-mail included the link to the survey that was therefore administered electronically. This allowed respondents to choose the moment for answering the survey. We considered that this would contribute to improve the quality of the data gathered. They were assured that the questionnaire was completely anonymous. Under these conditions we obtained a sample of 2.138 students that voluntarily completed the questionnaire that included 48 questions [18].

In a second step, we developed what we call the PIKA model of the image of science. This model describes the interaction between the citizens perception of science (P), their interest on the issue (I), their knowledge (K), and the disposition to act (A) regarding science, assuming that the image of science is running in the background when individuals act and make decisions in their everyday life. This model is described in the following section.

Considering all aforementioned, this paper is aimed at providing evidence in favour of the PIKA model of the image of science. To achieve this objective, this work rests on data from three Spanish studies that include different sampling strategies, from distinct populations, and in different years.

2. THE PIKA MODEL

We rely on the work of the neurologist Antonio Damasio to describe the image of science from a naturalistic approach. In this process, we first need to consider that neurons are organized in circuits and, consequently, the mind is the outcome of the organization of the circuits of neurons in big nets. In turn, these nets compose patterns of activation. These patterns are responsible of representing in the mind everything that happens, what is outside the brain, but also the products of its activity. Images are the result of these patterns of neural activation and include all sensorial modalities, not only vision [19]. Therefore, when we talk about the image of science we are not referring to a picture, but to the mental representation every citizen build as a result of his or her knowledge and experience with science. It also includes what they feel regarding science as a result of their interaction with it in their daily life. Images contribute to direct actions by means of two cerebral spaces that are separated to some extent: the images' space and the dispositions' space. The first is responsible of building explicit maps of objects and events during perception and reconstructing them during remembrance. Contents in this space are explicit and can be accessed when necessary. The dispositions' space includes all our memory and the neural devices we need to rebuild knowledge in the process of remembering. It also includes the activation patterns that translate into the actions implemented. Dispositions are necessarily unconscious, codified and latent, although their results are also translated into images [19].

According to our translation of the work of Damasio to the study of the image of science, this image has a direct correspondence with a neural net in the brain. The results of this and previous analysis allow us to depict a sector of the neural net of the image of science that includes six interrelated nodes (Fig. 1): interest, engagement, action, trust, knowledge and perception. This last factor includes in turn two sub-factors: attitude and opinion [20,21].

Considering all the above, we postulate that people shape an image of science as a result of their interaction with it in their daily life in a specific social environment. Simultaneously, the social environment influences the citizens' image of science as a result of the relationship of society with science. Notwithstanding, the image of science is also very complex. For this reason we have to focus on some of the factors that contribute to shape it. To date, the factors that have received more attention have been perception, interest, knowledge and attitudes about science. Therefore, the PIKA model describes the segment that includes the interaction among four dispositions: Perception, Interest, Knowledge, and Action (Fig. 2).

2.1 Science Perception

Perception is the cognitive process by which information from the environment is transformed into mental representations, images reflecting in our brain the external information processed according to our knowledge and prior experience. Our perception of the world is direct, immediate and without effort, that is to say, we do have none information regarding the processes that take place in our brain [19,22,23]. With respect to science, perception implies processing the scientific information of our environment that is mainly provided by the media [24], and rebuilding it by means of its assimilation to our mental maps. The PIKA model assumes that the perception of science includes two products: attitudes and opinions.

There is a great amount of definitions of attitude, and consensus on what means to have an attitude is far from being achieved, but there is wide agreement in considering evaluation as its main feature [25-27]. Each object or process to which people confront in their life-cycle acquires some biological value due to the function it performs to guarantee survival. In human beings' case, this value is also related to the "quality" of this survival in the form of welfare. Attitudes represent these values [19]. Hence, we define attitudes as dispositional value-laden images.

In Psychology, attitudes are closely linked to beliefs. Although the term "belief" is often used to represent the information the individual has of an object, this concept has great variety of meanings and connotations depending on the context or the discipline from which its study is tackled. Instead, the term "opinion" is more neutral and, hence, we use it to represent the connection of objects with attributes. Both terms (objects and attributes) are used in a general sense, making reference to each aspect of the person's world that may be discriminated.

When measuring attitudes and opinions there is great overlap. To differentiate between attitudes and opinions we start from the assumption that questions that include an "agree-disagree" response format are more probable to elicit opinions. This format places the respondents before the contingency of deciding to what extent the ideas expressed in the statement match with

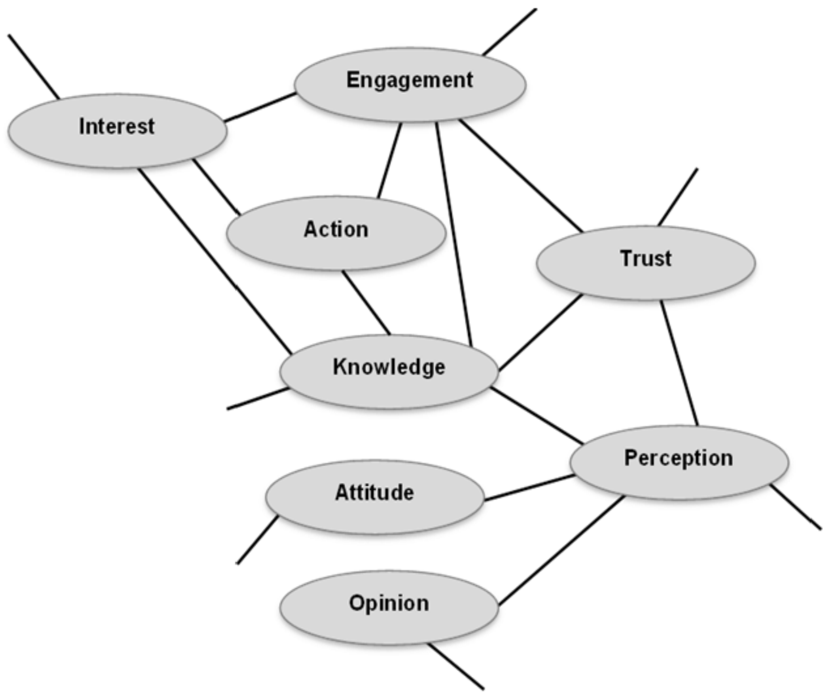


Fig. 1. Depict of a sector of the neural net that represents the image of science

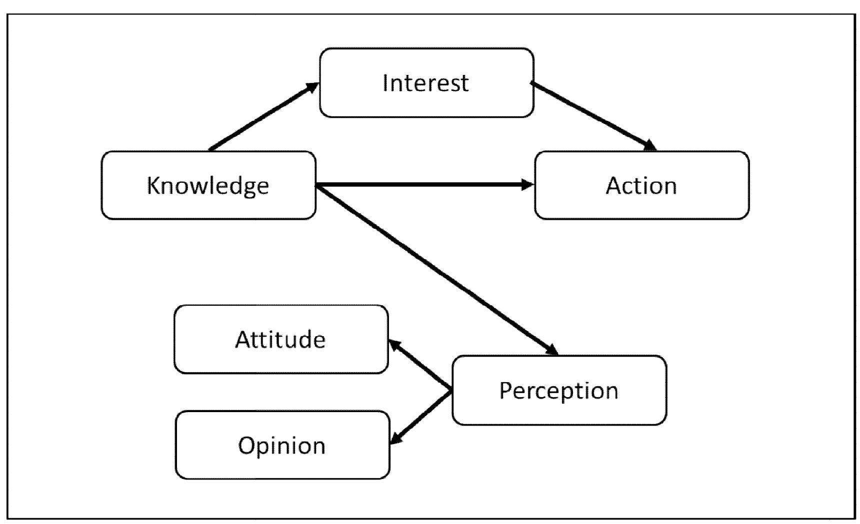


Fig. 2. The PIKA model

their own; or to what extent they agree or disagree with the statement as a result of what they know regarding the issue. On the contrary, questions with formulations in which respondents should value an entity (science and technology in this case) as a function of its benefits or harmful effects, or in terms of its advantages or disadvantages, better reflect the existence of an attitude [28,29]. The reason is that in answering these questions respondents have to wonder, not what they know regarding the issue, but how they feel about it.

2.2 Interest in Science

Interest is an almost omnipresent element in surveys of public perception of science that usually include three questions on the issue. In the one measuring informative interest, respondents have to express to what extent they are interested in the news of science, technology, scientific discoveries, technological developments, etc. A second one asks for general interest in science. The commonly used question is: “I would like to know to what extent you are interested in different issues?” followed by a list of topics: sports, arts and culture, politics, medicine and health, environment and ecology, food and consumer affairs, and science and technology. This question is accompanied by a third focused on the perceived level of information regarding the same topics. We consider that interest is dependent on knowledge and represents a general disposition towards science.

2.3 Knowledge about Science

The measurement of scientific literacy has been structured around four dimensions: 1) Understanding of basic theoretical constructs of science; 2) Understanding of scientific methods as probabilistic reasoning and experimental design; 3) Appreciation of science and technology results; and 4) Rejection of superstitious beliefs as astrology or numerology. However, the first dimension has been the most predominant in the surveys available to date. Questionnaires have been based primarily on the Science and Engineering Indicators of the National Science Foundation (NSF) in the US. A version of these items was included in both editions of the Spanish Foundation for Science and Technology (FECYT, in its Spanish acronym) survey. However, it is not clear that these questions actually measure scientific literacy [30-32]. For this reason, the PIKA questionnaire (the tool we developed in correspondence with the model) included a different approach to measure this factor. Specifically, the questions measuring knowledge of science were structured around five topics: cloning, stem cell, internet, nuclear energy and the Higgs boson. There were three questions for each topic: one regarding basic scientific constructs, another related to contemporary science, and the last one about meta-knowledge or knowledge of scientific controversies.

2.4 Actions Related to Science

The PIKA model assumes that actions are a key factor in shaping the image of science because people should be in condition to put science into practice. And this has to do with the citizens’ capabilities to make decisions and choose courses of action in a context in which science has a very important role in shaping their daily life [33].

It seems obvious that it is impossible to measure actions by means of a survey. As much, we can measure dispositions. And, as it is well known since 1934 from the studies of LaPiere on attitudes, what we say we will do has little to do with what we actually do [26]. But it seems also evident that to do something we first have to be willing to do it.

3. METHODOLOGY

3.1 Subjects

As we mentioned, we tested the PIKA model in three different samples from different years. Specifically, the 2006 and 2014 editions of the Survey on Social Perception of Science and Technology by FECYT, and the answers to the PIKA Questionnaire of a sample of students from several Spanish universities. The sample of the 2006 edition of the survey of FECYT is comprised by 7.056 subjects from 18 years of age, while the 2014 edition includes 6.136 people. These samples were obtained by multistage sampling, stratified, with selection of primary sampling units (municipality) and secondary units (sections) randomly and proportionally, and of the last units (individuals) by random routes and quotas of sex and age.

In the PIKA survey we contacted with approximately 25.000 students from the universities of Oviedo, Valencia, Valladolid, Salamanca, Complutense University of Madrid, and the School of Mining and Energy of the

Technical University of Madrid. We obtained 2.138 completed questionnaires with a response rate of 8.5%.

3.2 Variables

3.2.1 2006 and 2014 FECYT survey[1]

3.2.1.1 Perception

3.2.1.1.1 Attitude

P15a (2006). To what extent people associate science with: progress, dehumanization, richness, inequality, efficacy, risks, participation, elitism, power, dependency, well-being, decontrol. Scale from 1 (nothing at all) to 5 (totally).

P13 (2006), P14 (2014): The balance between positive and negative aspects of science and technology. The interviewees had to choose one of the following options: 1) the benefits of science and technology outweigh its harmful effects; 2) the benefits and harmful effects of science and technology are balanced; 3) the harmful effects of science and technology outweigh its benefits; and 4) I do not have an opinion on this issue.

P15 (2014): The balance between benefits and harmful effects of some specific applications of science and technology with the same options of P13 (2006) and P14 (2014):

Cloning
Nuclear energy
Stem cell research
Fracking
Internet
Mobile telephony
Wind towers
Genetic disease diagnosis

3.2.1.1.2 Opinion

P11 (2006): Level of agreement with statements on science and technology (totally disagree, disagree, neither agree nor disagree, agree, totally agree): 1) We give too much value to scientific and technological knowledge compared to other forms of knowledge; 2) science and technology provide the best and most reliable knowledge of the world; 3) scientific research and technology will help to cure illnesses such as AIDS, cancer, etc.; 4) science and technology applications have created health risks; 5) science and technology applications are leading to the loss of jobs; 6) thanks to science and technology there will be more job opportunities for future generations; 7) science and technology applications are creating an artificial and inhuman lifestyle; 8) science and technology are making life easier and more comfortable for us; 9) science and technology will help to get rid of poverty and hunger in the world; 10) science and technology are widening the gap between rich and poor countries; 11) science and technology contribute to improve the natural environment; 12) science and technology are creating serious environmental problems; 13) science and technology are not concerned about true social needs; 14) science and technology enable social welfare to be improved.

P12 (2006): Level of agreement with statements on science and technology (totally disagree, disagree, neither agree nor disagree, agree, totally agree): 1) Science and technology are the maximum expression of prosperity in our society; 2) science and technology are useful, above all, to solve problems; 3) science and technology solve problems, but also create them; 4) science and technology are a source of nightmares for our society.

P21 (2006 and 2014): The degree of agreement with various statements on the role of scientific knowledge in decision-making and public participation in issues related to science and technology (totally disagree, disagree, neither agree nor disagree, agree, totally agree): 1) The work of scientists should be guided by those who pay for scientific research; 2) scientist should decide the course and aim of their scientific activity[2]; 3) if it has not been proven scientifically that new technologies can cause severe harm to humans or the environment, it is erroneous to impose restrictions on them; 4) while the consequences of a new technology are not well known, action should be guided by caution and the technology's use should be controlled; 5) scientific knowledge is the best basis for drawing up laws and regulation; 6) in the drawing up of laws and regulation, values and attitudes are as important as scientific knowledge; 7) decisions on science and technology are best left with experts; 8) citizens should assume a more important role in decisions on science and technology. Only in 2014: 1) we cannot trust that

[1] *Available at: http://icono.fecyt.es/informesypublicaciones/Paginas/Percepcion-Social-de-la-Ciencia.aspx.*

[2] *Questions 1 and 2 are only present in 2006.*

scientists tell the truth regarding controversial issues because they are increasingly more dependent on the funding of industry; 2) researchers do not allow those who finance their work influence the results of their research; 3) science and technology can solve everything; 4) always there will be things that science cannot explain.

3.2.1.2 Interest

P1: Spontaneous informative interest in science and technology (mentioned or not).

P5 (2006), P2 (2014): I would like to know if you are nothing, little, something, quite or very interested in science and technology.

P6 (2006), P3 (2014): I would like to know if you are nothing, little, something, quite or very informed regarding science and technology.

3.2.1.3 Knowledge

P34 (2006), P31 (2014): Knowledge of basic scientific facts (true or false):

1. The Sun goes around the Earth.
2. The oxygen we breathe comes from plants.
3. Antibiotics kill viruses as well as bacteria.
4. The continents have been moving for millions of years and will continue to move in the future.
5. Lasers work by focusing sound waves.
6. All radio-activity is man-made.
7. The centre of the Earth is very hot.
8. Human beings developed from earlier species of animals.
9. Electrons are smaller than atoms[3].
10. The earliest humans lived at the same time as the dinosaurs.
11. Stem cells can be extracted from the umbilical cord of mammals[4].
12. When a person eats a genetically modified fruit her genes can also be modified.
13. Mobile phones produce electromagnetic fields.

P30 (2014): Suppose a group of scientists is assessing the efficacy of a drug used to treat high blood pressure. Which option will be the most useful to establish the efficacy of the drug?: 1) Ask the patients how they feel and see if they notice any effect; 2) analyse each of the drug components separately; 3) give the drug to some patients but not to others, then compare what happens to each group; 4) use their knowledge of medicine to stablish the efficacy of the drug.

P31 (2006), P27 (2014): Perception of the level of the scientific education received (very low, low, normal, high, very high).

P32 (2006): Utility of the received scientific education for different dimensions of daily life (scale from 1, useless, to 5, very useful): Profession, comprehension of the world, people relationships, consumer behaviour, and formation of political and public opinions.

D7 (2006), D8 (2014): Highest level of completed education (from 1, illiterate, to 8, postgraduate studies).

3.2.1.4 Actions

P9 (2006), P4 (2014): Visit science or technology museums, or science centres; participate in some science "week" activity, in the last twelve months (yes, no).

P10 (2006): Sources to get information of science and technology: Internet, books, newspapers, radio, science magazines, television (yes, no).

P20 (2014): Be willing to incorporate science to altruistic donations of money (yes, no).

3.2.2 PIKA survey[5]

3.2.2.1 Perception

3.2.2.1.1 Attitude

P18. To what extent people associate science with: progress, risks, rigor, security, utility, boredom, economic development, efficacy, complexity, mistrust, interest. Scale from 1 (nothing) to 9 (a lot).

3.2.2.1.2 Opinion

P25. To what extent respondents share opinions of citizens from a previous study (totally disagree, disagree, agree, totally agree): a) The ideas of scientists are leading us too far; b) it is

[3]*Only present in 2006.*
[4]*Questions 11 to 13 only present in 2014.*

[5]*Available at: http://rdgroups.ciemat.es/documents/69177/122473/Anexo_Cuestionario+maquetado.pdf/2972eeac-a576-444f-9c44-ed213c83d990.*

necessary to somehow control what scientists do; c) if we control in excess the activity of scientists, their creativity will be limited; d) if we are to control the scientific activity, it will be better if it is in the phase of development or application; e) there should be no limits for science; f) scientists should be free to investigate; if not, the risk exists of them doing what politicians want; g) if we attach too much importance to risks, we could be excluded from progress; h) we must continue exploring things to ensure that we go in the right direction; i) when the consequences of a scientific discovery are unknown, it is necessary to control its use; j) we live in a free society where knowledge should be pursued.

3.2.2.2 Interest

P8. The meaning of being interested in science by valuing some indicators (from 1, it is a bad indicator, to 4, it is a good indicator): a) visit museums and science and technology exhibitions, b) be aware of new technological developments, c) read news of new scientific discoveries, d) be aware of news regarding negative consequences of science and technology, e) know the way scientists develop their work, f) enjoy watching science TV series like CSI, Bones or Criminal Minds, g) want to become a scientist.

3.2.2.3 Knowledge

We were aimed at measuring knowledge of current science on topics in which some kind of social debate or controversy exists to also assess the dimension of meta-knowledge. Questions were organized around five topics. Each participant responded to two randomly selected topics:

A. Stem cells:

1. Which one is correct?

   a. Plants do not have cells.
   b. All animals are unicellular.
   c. Cell is the unit of life.

2. Which one is correct?

   a. Stem cells are present only in women who have just given birth.
   b. The egg and sperm are stem cells.
   c. Stem cells can be extracted from the umbilical cord of mammals.

3. There is currently a debate on the cultivation and use of embryonic stem cells due to:

   a. The consideration of human embryos as persons.
   b. The risks associated with the contamination produced by these cells.
   c. The recent prohibition of in vitro fecundation in Spain.

B. Nuclear energy:

1. “Energy is neither created nor destroyed, it simply transforms”:

   a. It is an advertising slogan.
   b. Describes Newton’s First Law.
   c. Enunciate First Law of Thermodynamics.

2. Energy production in nuclear power plants is done by:

   a. Nuclear fusion.
   b. Nuclear fission.
   c. Combustion of radioactive elements.

3. After Fukushima’s accident, the debate on nuclear power plants was reopened. Tell us, please, what option best reflects the content of this debate:

   a. Nuclear power plants are completely safe in areas where there is no risk of tsunamis.
   b. Nuclear power plants are completely safe in countries free from the threat of terrorism.
   c. Nuclear power plants will never be able to be considered completely secure.

C. Social networks:

1. Social networks:

   a. Always have existed, Internet simply has provided them with a new space.
   b. Did not exist before the emergence of Internet.
   c. Did not exist before the emergence of Facebook.

2. Android is:

   a. A social network.
   b. A computer application.
   c. An operating system.

3. Facebook is a social network, but also a company with great economic benefits. These gains come mainly from:

   a. Public subventions and fees that companies pay to have an available space.
   b. Economic exploitation of the photographs uploaded by users to their accounts.
   c. Tracking the activity of their users on Internet.

D. Cloning:

1. If we define cloning as the generation of a living organism with the same genetic load of another, which option is correct?

   a. Does not occur spontaneously in nature.
   b. Occurs spontaneously in nature.
   c. Never has occurred, artificially nor in a natural way.

2. Therapeutic cloning:

   a. It is an assisted reproduction technique employed widely for decades.
   b. It is not oriented to cloning humans or animals, but tissues or organs.
   c. Reproduces in laboratory the development of embryos of identical twins.

3. The debate around cloning is due to:

   a. Its use for producing genetically modified foods.
   b. Its use for the reproduction of human beings.
   c. Its indiscriminate use in the Third World.

E. Higgs boson:

1. Where are neutrons in the atom?

   a. In the nucleus.
   b. Outside the nucleus.
   c. Orbiting around the nucleus.

2. What is the Higgs boson?

   a. A chemical reactive.
   b. A particle.
   c. A fossil.

3. How was the Higgs boson discovered?

   a. By a chemical reaction.
   b. By an experiment designed to find it.
   c. By an archaeological expedition.

3.3 Analysis

All analyses were carried out with SPSS version 22.0 and AMOS 18.0.

We used Structural Equation Modelling (SEM) to test the PIKA model. SEM is a statistical technique adopting a confirmatory approach to analyse a structural theory on some phenomenon. The hypothesized model can be tested statistically in a simultaneous analysis of all the variables to determine to what extent it is consistent with data. The final conclusion depends on goodness-of-fit [34].

There is considerable consensus regarding the convenience of choosing the RMSEA and CFI indices to assess SEM goodness-of-fit [35,36]. RMSEA values below 0.05 indicate good fit, while those as high as 0.08 are considered reasonable [34]. In assessing the adequacy of a model, parsimony also has to be considered. There is agreement that the PCFI should be the parsimony index of choice [34]. A recommended rule of thumb makes reference to PCFI values above 0.50 with CFI indices around 0.90 [37]. Finally, Hoelter's Critical N estimates the sample size that would be sufficient to yield an adequate model fit for a $\chi 2$ test. Hoelter proposed a value above 200 as an indicator of model adequacy [38].

The approaches employed in SEM are based on the assumption that the variables included in the model are continuous and have a multivariate normal distribution. Multi-item variables are then transformed into indicators by summing all the items to comply with the requirement of having continuous variables. Variables measuring perception of science might be reflecting different concepts and, therefore, its internal consistency is assessed by means of Cronbach's alpha reliability coefficient. Although there are no clear standards, it is considered that 0.70 is the minimum acceptable value [34].

All variables or indicators described in the Methodology section have been included in the initial SEM for each sample, but the criterion was established that only variables with loadings of 0.30 or over are kept in the final SEM [39]. Nevertheless, SEM models require at least two indicators for each factor. Hence, when the factor is explained by only two variables, it has been necessary to keep them in the model even though the loadings were below 0.30.

Prior to testing the validity of the model, the problem of its identification had to be addressed. Specifically, the identification status of the higher-order portion of the model reflecting the four constructs: Perception, Interest, Knowledge and Action. A strategy to resolve the issue of excess of identification in this section of the model is to place equality constraints in some residual terms [34]. Hence, the residual variances of Perception and Action were equalized considering that these are the only constructs not related in our model (Fig. 2).

4. RESULTS

In the 2006 edition of the FECYT survey multiple indicators can be obtained. With respect to the perception construct, there are two indicators measuring attitude (P15 and P13), and three measuring opinion (P11, P12, and P21). P15 focuses on the identification of science with a set of characteristics, P13 asks for the balance between benefits and harmful effects, P11 includes 14 positive and negative statements regarding seven issues related to the impact of science on society, P12 focuses on the utility of science, and P21 consists of eight statements on science regulation. Cronbach's Alpha value for P15 is high (0.91), for P11 is moderate (0.82), and for P12 and P21 is low (0.72 and 0.75 respectively). The value of this statistic increases with the number of items and hence both values could be considered acceptable [31] considering that P12 only includes four items, and P21 addresses a wide diversity of issues with only eight items.

Other indicators created were: 1) ISE (Informal Science Education), calculated as the sum of the number of visits to science museums plus the number of participations in activities of science weeks in the last year (P9); 2) IC (Information Consumption), result of summing all the sources consulted to be informed about science (P10); 3) KBC (Knowledge of Basic Constructs), obtained summing all the correct replies to the test of scientific literacy (P34); and 4) Utility, result of summing the attribution of utility of scientific education in all the dimensions of everyday life included in the question (P32).

The edition of 2014 of the FECYT survey only provides the opportunity of obtaining indicators for the attitude construct as a function of the balance between benefits and harmful effects of science and technology. P14 refers to the global valuation of science and technology in these terms. P15 is the result of summing the assessments of benefits and harmful effects of several applications of science and technology (Cronbach's Alfa = 0.76). As in the 2006 edition, a KBC and ISE indicator was constructed for the Knowledge and Action factors respectively. In this edition of the survey, the KBC index also includes one item measuring knowledge of the scientific method (P30).

The PIKA questionnaire only includes one question to assess "attitude" and another for "opinion", and so it not has been possible to use composite indexes for the perception construct in the SEM. With respect to knowledge, respondents of this study were confronted with two of the five topics measuring knowledge of science, randomly selected. Each topic includes two questions regarding current science and one of knowledge of controversies. Therefore, the KBC index is the result of summing four items, and the meta-knowledge index two items. Finally, the IC index is obtained summing all the sources consulted to be informed about science.

The descriptive statistics of the significant variables in the definitive SEM are shown in Table 1. There are two facts standing out. First, in all the variables included the mean is nearer the maximum value than the minimum, with the exception of ISE and IC indicators. Therefore, a skewed and positive image of science is observed in the three samples studied. But according to the ISE and IC indicators, engagement is less evident. Second, the comparison of the 2006 and 2014 FECYT survey editions shows that the image of science in the Spanish population has become more positive with time.

The final SEM models are shown in Figs. 3 to 5. Residuals and terms of error are not depicted to simplify the graphs considering that they are necessary for developing the analysis but not to interpret the results. Goodness-of-fit indices are good in the three models, with values of CFI index from 0.903 in the PICA sample to 0.972 in FECYT 2006. RMSEA is under 0.05 in all the models, and PCFI ranges from 0.676 in FECYT 2014 to 0.747 in FECYT 2006. Hoelter's Critical N is over 200 in the three models. The best results are obtained in the 2006 FECYT sample because it offers the possibility of obtaining aggregated indicators to explain all the theoretical constructs. Conversely, the worst results are obtained in the PIKA survey for the opposite reason.

Results from FECYT 2006 are shown in Fig. 3. As predicted, Knowledge significantly contributes to explain Perception, Interest and Action related to science and technology with factor loadings from 0.62 in Perception to 0.72 in Action. Interest also contributes to explain Action, being this the best explained construct (88% of its variance explained by the other two constructs). The percentage of variance on Perception accounted for by Knowledge is small (39%), indicating that there are other important factors to consider. Perception is significantly explained by Knowledge. It is remarkable that Attitude is completely accounted for by Perception. Action is the construct worst identified. The weight of the IC indicator is reasonable, but the weight of the ISE indicator is very weak. In fact, it is kept in the model because at least two indicators are necessary to explain a construct.

The model for the sample of FECYT 2014 is rather similar to the one of FECYT 2006 (Fig. 4). The regression weights of Knowledge in Interest and Action are a bit smaller, but this can be attributed to the absence of the Utility indicator in the Knowledge factor. If this indicator is deleted from FECYT 2006 model, the regression weights are almost identical. Conversely, the regression weight from Knowledge to Perception is higher (0.90), but the regression weight of Perception in Opinion (and the variance accounted for by) is smaller. This is probably due to the fact that in the sample of 2014 this last construct is only defined by means of a multi-item variable (P21) instead of by three indicators as in 2006. Opinion is best defined by factors accounting for the features of science and society relationship (P21.6 to P21.10) and worse by factors reflecting the functioning of science (P21.1, P21.2, and P.21.4). The most important factor is the opinion of the role of attitudes and values regarding the elaboration of laws and regulations. Action is also the worst defined construct due to lack of appropriate indicators.

Table 1. Variables included in the SEM. descriptive statistics

Variables	FECYT 2006			FECYT 2014			PIKA 2014		
	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.
				Perception					
Attitude									
P13 (2006), P14(2014)	2.07	0	3	2.29	0	3	-	-	-
P15a (2006)	37.97	0	60	-	-	-	-	-	-
P15 (2014)	-	-	-	17.38	0	27	-	-	-
P18	-	-	-	-	-	-	66.8	0	99
Opinion									
P11 (2006)	42.93	0	70	-	-	-	-	-	-
P12 (2006)	12.41	0	20	-	-	-	-	-	-
P21 (2006, 2014)	25.22	0	40	31.52	0	50	-	-	-
P25	-	-	-	-	-	-	27.21	9	36
				Interest					
P5 (2006), P2 (2014)	2.83	0	5	3.19	0	5	-	-	-
P6 (2006), P3 (2014)	2.47	0	5	2.83	0	5	-	-	-
P8a	-	-	-	-	-	-	2.6	1	4
P8b	-	-	-	-	-	-	3.15	1	4
P8c	-	-	-	-	-	-	3.29	1	4
P8d	-	-	-	-	-	-	2.90	1	4
P8e	-	-	-	-	-	-	2.91	1	4
				Knowledge					
KBC	5.71	0	10	8.94	0	13	2.99	0	4
P31 (2006), P27 (2014)	2.31	0	5	2.42	0	5	-	-	-
Utility	11.45	0	25	-	-	-	-	-	-
Education	3.12	0	5	3.48	0	5	-	-	-
Meta-knowledge	-	-	-	-	-	-	1.46	0	2
				Actions					
ISE	0.34	0	7	0.35	0	7	-	-	-
IC	1.59	0	3	-	-	-	2.82	0	8
P20	-	-	-	1.75	0	3	-	-	-
P15	-	-	-	-	-	-	3.25	1	4

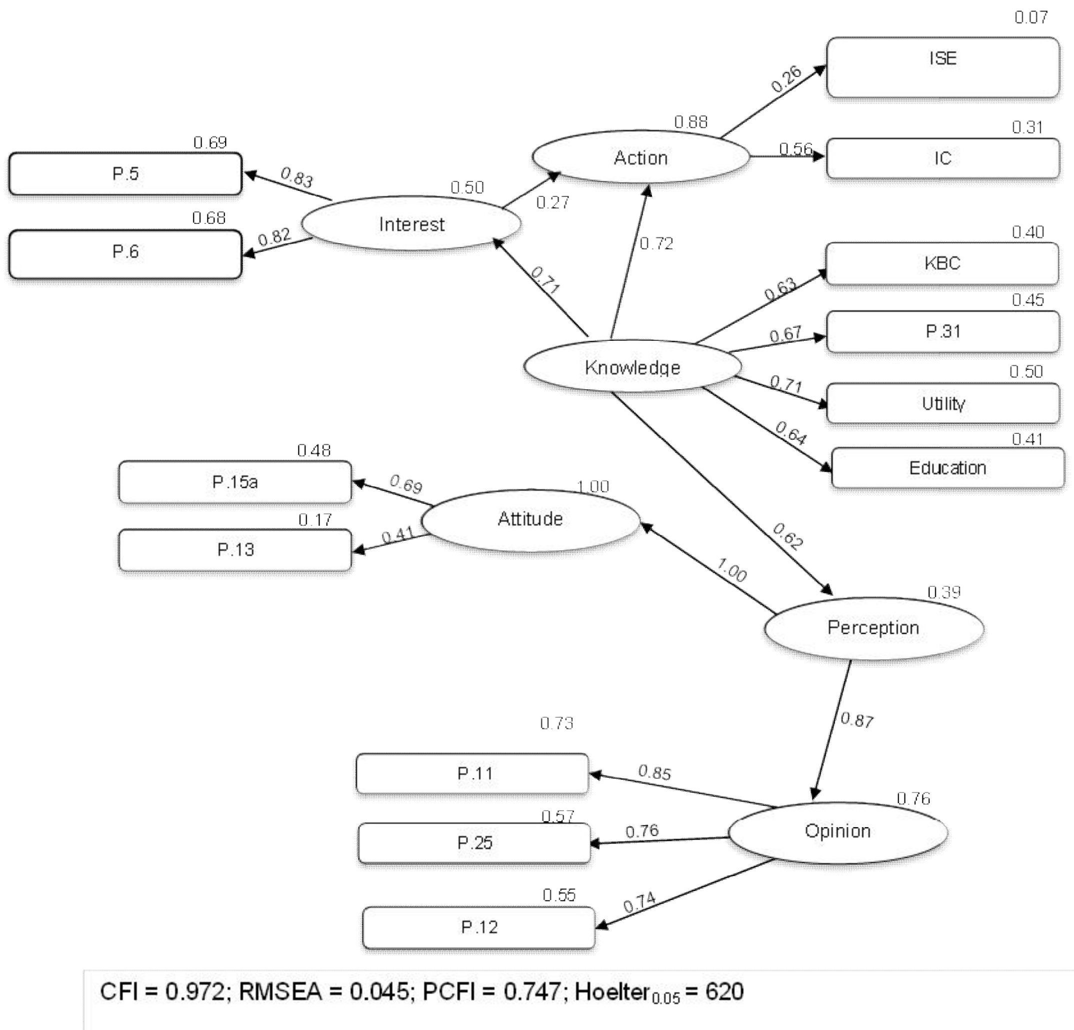


Fig. 3. SEM. PIKA model. FECYT 2006

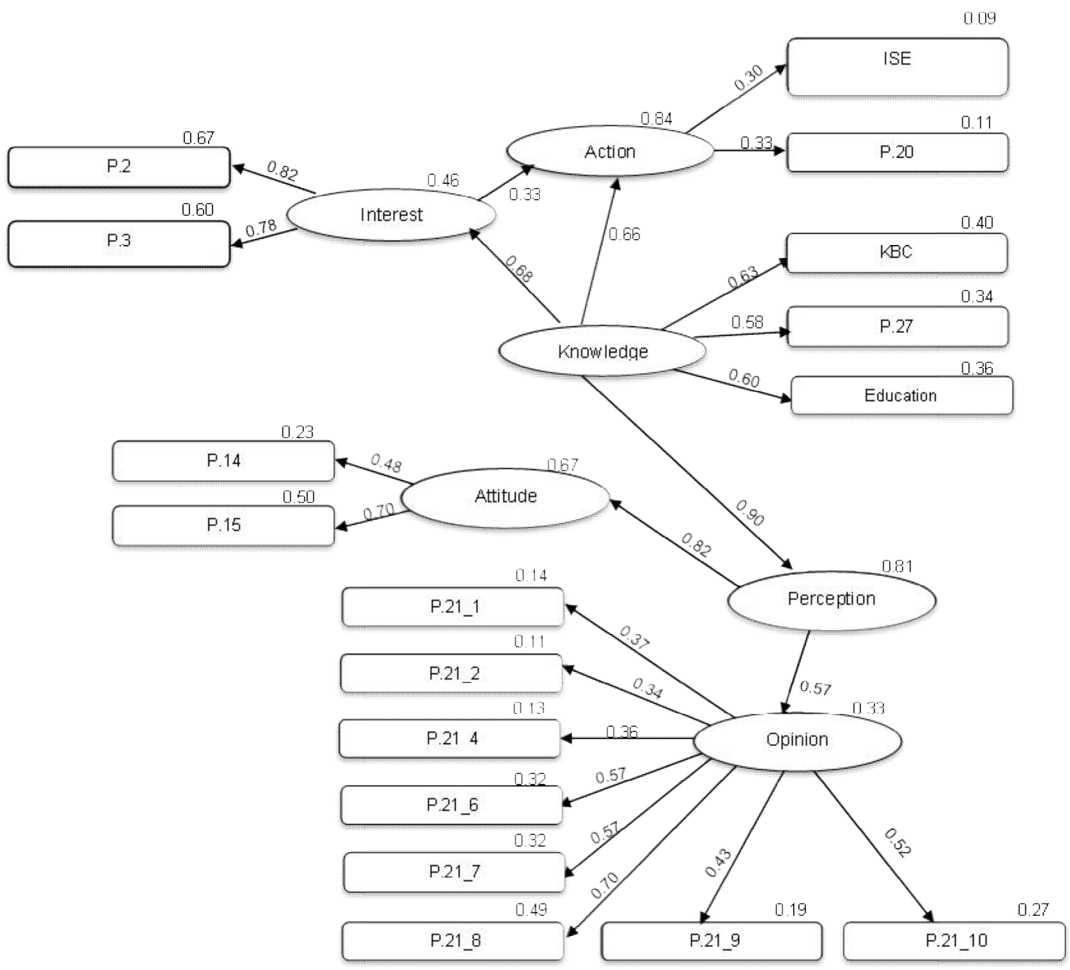
The PIKA questionnaire includes different indicators than the FECYT surveys and, hence, the model is not exactly the same (Fig. 5). Nevertheless, it keeps the structure with one exception: Interest does not significantly contribute to explain Action in this model.

The reason can be attributed to the inclusion of a new indicator of this last factor: science orientation (P15). This factor has more to do with a scientific attitude that with an action. Considering that is more important than the IC indicator, it seems that participation in ISE activities or the consultation of different sources to get informed about science are dependent on Knowledge and Interest. Conversely, the disposition to adopt a “scientific” perspective in everyday life seems to be more related to Knowledge and less to Interest. Anyway, the important influence of Knowledge over the other constructs is very remarkable considering that is badly defined. Although the questionnaire includes 15 questions of knowledge, distributed around five topics, respondents were randomly assigned to only respond questions of two topics and, hence, meta-knowledge and literacy include, together, only six items (two and four respectively). Besides, all the subjects of the PIKA sample were undergraduates and, for this reason, education is not a variable to include in the model (is a constant).

With respect to Interest, the questionnaire does not ask about the level of information of respondents, but instead tries to better specify what means to be interested in science and technology. Anyway, factor loadings show that being informed or be willing to be informed are the best predictors of Interest. Perception, Attitude, and Opinion are worst defined in comparison with the FECYT surveys and, above all, the sample of 2006, because there is only available a multi-item question and not different indicators. Attitude is best explained by the association of science with utility, efficacy, and progress. The only attribute with a minimum negative connotation (complexity) contributes significantly to explain Attitude, but to a lesser extent. It is also evident the lack of significant variables to explain the Opinion construct (its explained variance is 26%). In any case, all the items contributing to explain this factor reflect a very positive opinion about science pointing to the need of guaranteeing scientists' freedom of research. Nevertheless, it has to be kept in mind that the PIKA questionnaire was administered to a biased sample of university students interested in science.

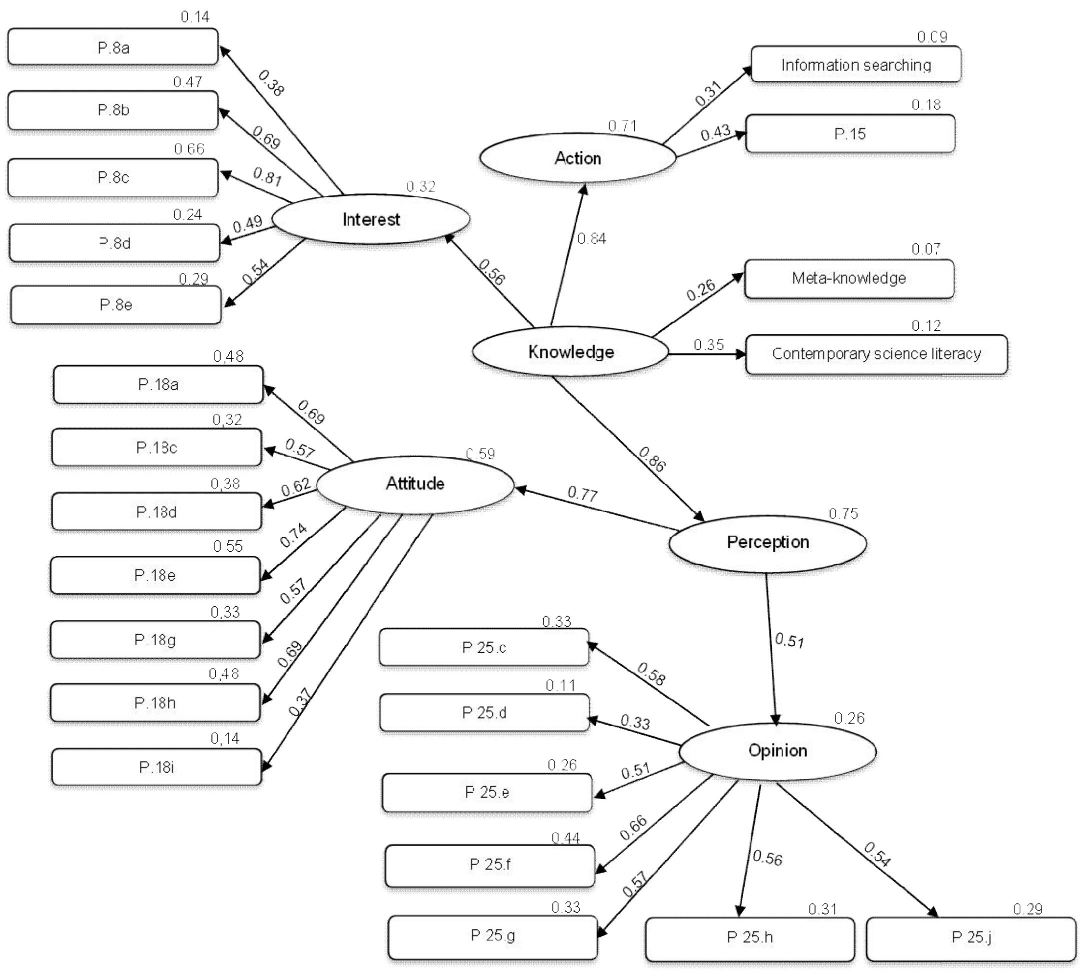
5. DISCUSSION

In a work published in 1989 in *Nature*, titled Public Understanding of Science, Durant, Evans and Thomas pointed to interest as the trigger factor of the public understanding of science because, in their opinion, interest is necessary for wanting to know and having attitudes regarding science. The results they obtained after polling a sample of British and American citizens regarding these issues led them to conclude that people was interested in science but had a poor knowledge of it [40].



CFI = 0.915; RMSEA = 0.047; PCFI = 0.676; $Hoelter_{0.05}$ = 515

Fig. 4. SEM. PIKA model. FECYT 2014



CFI = 0.903; RMSEA = 0.045; PCFI = 0.676; $Hoelter_{0.05}$ = 463

Fig. 5. SEM. PIKA model. PIKA questionnaire

Notwithstanding, most part of the efforts made since then to bring science closer to citizens have been aimed at fostering their interest in science. In words of Helga Nowotny, these efforts had contributed to create low cost realities. These are very “cheap” to consume because they depend on the immediate flow of images and sounds and, consequently, are a very successful commercial product in our society [41].

In this contribution we assume that knowledge is a key disposition in shaping the image of science. It is undoubted that the role of knowledge in the public image of science is controversial. We consider that this controversy is a direct consequence of the assumptions of the deficit model. According to this model, there is a linear relationship between knowledge and attitudes toward science and the core of this relationship can be summarized as: “the more you know, the more you love it” [3]. Despite the efforts made, research has been unable to provide concluding evidence about this relationship. On the other hand, the criticisms of the deficit model, shared by the authors of this study, have placed the analysis of the influence of knowledge on the public image of science in the background. However, we believe that these criticisms should not lead us to ignore the importance of knowledge to shape the public image of science. Furthermore, the deficit model framework is not able to explain why people more knowledgeable of science and technology show sceptical attitudes, while people less knowledgeable strongly support science [42]. It is possible that the question is not “the more you know, the more you love it” but, “the more you know, the more you opine” [29], and also, “the more critical your opinion”. We are not advocating for the significance of knowledge from a position of superiority in which citizens are denied their ability to properly understand the role of science (a criticism of the deficit model). Instead, we lean on the fact that knowledge strengthens and enriches the conceptual maps of science [43]. As a result, citizens are better able to apply these maps to direct their daily life actions [33].

We found evidence supporting the hypothesis that the image of science is shaped by Knowledge, Interest, Perception, and the disposition to Act regarding science. In all the models analysed we found that knowledge is a key factor and influences the other factors considered. Besides, the results from the edition of 2006 of the FECYT survey show an improvement in the percentage of variance explained in Interest when Knowledge is better specified. In this sense, it is interesting to highlight the importance of two questions: the one asking for the perception of the level of the scientific education received at school (P31 in 2006 and P27 in 2014), and the one that focus on the perceived utility of this education for some daily life spheres (P32, only in 2006). Both are key questions if we are aimed at engaging citizens in science: they reflect the importance of feeling able to face up with science, and of perceiving that this capacity is useful in daily life. And they point to the existence of some kind of feedback loop between knowledge and interest.

We also found evidence that Perception includes two factors: the attitude to science that we defined as a value laden dispositional image, and the opinion we have about it. This evidence proceeds from the analysis of three Spanish surveys implemented in two periods of time (2006 and 2014), using different sampling strategies (probabilistic and convenience), and with different questionnaires that, consequently, provided different indicators of the postulated dispositions. Having the possibility to compare different sources of data is of great importance because it shows that our results are not dependant on the sample or the questionnaire.

Additionally, we found evidence of the importance indicators have in the development of the model. SEM is a family of statistical multivariate models that allow the estimation of, simultaneously, the effects and relationships among multiple variables. They enable to postulate both the kind of relationship that is expected to find among the variables, and its direction to subsequently estimate the parameters specified by the relations proposed at the theoretical level. SEM are also denominated confirmatory models because they permit to “confirm” the relationships that stem from the explicative theory used as reference. SEM obtain the best results with few quantitative variables (around 10 and below 20). Nevertheless, public opinion surveys provide nominal or ordinal variables. To solve this limitation, researchers can obtain indicators sum of different variables [44]. But to obtain these indicators, variables need to represent the same construct, i.e., there must be internal consistency among them. SEM also requires at least two indicators of each construct or factor. Being in conditions to comply with both requirements is a difficult task when working with public perception of science surveys. This makes our results especially valuable. And for the same reason, the best goodness-of-fit results are obtained in the FECYT 2006 survey. Data obtained in this study offer better opportunities to transform multi-item variables into single indicators by summing all the items. Besides, it provides at least two of these indicators to explain each construct. This result gives insight on how we should design the questionnaires if we want to understand the way citizens shape their image of science. The first version of the PIKA questionnaire, although innovative in the design, was limited by its broad scope. We are about to test a second version of the PIKA questionnaire that has been adapted considering the findings of this study.

In any case, the difficulties in defining the Action factor are obvious. There is no doubt that actions cannot be objectively measured by means of a questionnaire. But it is certainly possible to obtain a valid approximation if the questionnaire includes items about the disposition to act. Nevertheless, there is scarce information about this issue in the available questionnaires. We need to design the proper questions to advance in the development of good indicators that measure actions related to science. To achieve this objective, a theoretical framework is needed to define what actions or dispositions of behaviour are based on the possession of scientific information, or on the cognitive restructuration originated by the consumption of scientific information [45]. This remains pending for future studies.

Finally, SEM are based on the assumption that the variables included in the model have a multivariate normal distribution. Given that SEM is based on the analysis of covariance structures, evidence of kurtosis is a matter of special concern to guarantee multivariate normal distribution [34]. To assess multivariate normal distribution, the calculation of multivariate measures of kurtosis could be necessary [46]. However, the violation of the assumption of normality may contribute to the rejection of accurate models, not to the confirmation of inaccurate ones [47]. Additionally, it is also established that to avoid problems when data violate the assumptions of multivariate normality, sample size need to adjust to a ratio of 15 respondents for each parameter [39]. This study complies with this requirement. Therefore, it has been not necessary to obtain Mardia's normalized estimate of multivariate kurtosis.

6. CONCLUSIONS

As different authors have repeatedly pointed out over a period of more than 20 years, it is necessary to improve our scientific understanding of the public to better understand the relationship of citizens with science [48-51]. This study makes a contribution to this understanding providing evidence in favour of the PIKA model. This model acknowledges that by interacting with science in their social environment, people generate an image of science in their mind that determines how they react to it. This image depends on knowledge, perception, and interest. In turn, interest and knowledge have a direct influence on the disposition to act regarding science. It is possible that perception also develops a significant role in determining the way to act regarding science, but this is something to be explored. We also need better indicators of the factors that give shape to the image of science.

As we mentioned in the introduction, criticisms to central assumptions and theses of the deficit model approach, opened up the research on the relationship between science and society to different perspectives. The more recent puts its focus in the need to engage the public in science [9]. However, if we continue not properly understanding the public, we cannot assure that citizens want to engage in science. This is something that needs to be explored, taking into account that, the demand for engagement, if is not accompanied by the capacitation of citizens, places them in a difficult situation. First, citizens need resources to engage, being information and knowledge two of the most important [52]. Second, they also must want to engage, and some available evidences show that citizens do not participate when the possibility is offered [25]. The reasons behind this fact need to be explored.

The question is that although citizens seem to reject to be passive spectators, this rejection not necessarily imply that they are willing or feel themselves able to be protagonists with all the consequences that this entails. Fortunately, the percentage of people interested and knowledgeable of science to the extent of being consumers of science seems to be increasing worldwide. But this does not mean that this group of consumers will participate in science policy. Because scientific issues are complex, and to participate, people need to be specialized [53]. Taking this into account, we consider that by improving our knowledge about the citizens' image of science we will be better able to achieve the aim of empowering citizens to engage in science.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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