Attitudes towards Science among Spanish Citizens.

The Case of Critical Engagers

Montaña Cámara

Department of Food Science and Nutrition, Pharmacy

Complutense University of Madrid

Plaza Ramón y Cajal s/n

28040 Madrid, Spain

Corresponding author. E-mail: mcamara@farm.ucm.es

Ana Muñoz van den Eynde

Scientific Culture Research Unit, CIEMAT

Avenida Complutense, 40. Edificio 1, Despacho 030

28040 Madrid, Spain

E-mail: ana.munoz@ciemat.es

José A. López Cerezo,

Department of Philosophy

Campus Humanidades

University of Oviedo

33011 Oviedo, Spain

E-mail: cerezo@uniovi.es

Abstract: Using data obtained from Spanish surveys on the public perception of science, this paper presents a critical review of current practices of population profile segmentation including the one-dimensional representation of perceived risks and benefits, and of the systematic underestimation of critical attitudes to the social impact of science and technology. We use discriminant analysis to detect a somewhat hidden cluster in the Spanish population which we call "critical engagers". These individuals are critically and socially responsible and are not reticent about expressing concern regarding scientific-technological change. While they hold an overall positive attitude towards change of this kind, they are at the same time well aware of the risks posed by particular fields of application. We highlight the academic interest and political value of these individuals, attributing to this population a mature and intelligent stance which may well be employed in enhancing the relationship between science and society.

Key words: scientific culture, critical engagers, risk/benefit perception.

INTRODUCTION

As noted by Jon Miller (2012), the proper functioning of a democratic society depends not only on freedom of choice and freedom of information, but also on the capacity of its citizens to understand proposals and the terms of the discussion of alternatives. In a world increasingly transformed by technological change, this capacity must be understood as the possession of a "civic" scientific culture for understanding the issues of general interest related to science and technology (S&T) in order for citizens to be able to form an opinion and participate in democratic life.

Traditionally, the objective of promoting scientific culture and gaining social support for S&T has been seen as a process of rectification of deficits. Martin Bauer and colleagues (Bauer, Allum and Miller, 2007) have identified the two main periods by means of the so-called *paradigms* of scientific literacy and public understanding (of science). In the first, the predominant trend from the 1960s to mid-80s, a lack of knowledge (cognitive deficit) was attributed to the public that supposedly explains its negative perception of science and opposition to certain technologies, disqualifying lay citizens in public discussion or decision making and calling for greater efforts in education and communication. In the second of these paradigms, particularly prevalent from the mid-1980s to the late 1990s, the main challenge is not simply a lack of knowledge, but rather the lack of a favorable attitude to science: the problem is understood as an attitude deficit. In this reading of the problem from a realistic agenda, what ought to be encouraged is the support of science by society, promoting its favorable perception among citizens. Although marking prevailing trends in different periods, these paradigms largely continue to coexist today. Furthermore, they generally presuppose the premise that the better one's knowledge of science, the better one's attitude towards it (the so-called "axiom of Public Understanding of Science (PUS)": *the more you know, the more you love it*).

A recent critical current in this field is pointed to by a new paradigm also identified by Bauer, Allum and Miller (2007), the so-called "science in society" or "public engagement in science" paradigm. Rooted in STS scholarship on public participation (e.g., Petersen, 1984, Shrader-Frechette, 1985), this approach emerged in the mid-90s and has been upheld by authors such as James Wilsdon and Brian Wynne (e.g., Wynne, 1993; Wilsdon et al., 2005; Wilsdon, 2008; Wynne, 2014). In this approach, the main deficit does not lie in citizens, but in scientific institutions and the S&T system due to their prejudices about a supposedly ignorant and hostile audience, and in their inability to get in tune with the concerns of citizens and generate confidence within the public at large. While this new paradigm does not boast –at least for the time being– much analytical rigor or an articulated research program, it does have the virtues of considering traditionally neglected key elements (such as trust) and signaling the need for revising the axiom of PUS.

In the spirit of the new paradigm, over the last decade a number of authors (e.g., Bauer, Allum, Miller, 2007) have highlighted the severe limitations of the axiom of PUS and traditional approaches to the general objective of promoting a rapprochement between science and society, though without sacrificing the quantitative approach of traditional paradigms. This critical trend has revealed new ways of understanding what it means to be scientifically literate, e.g., in terms of the role of critical attitudes or in the practical dimensions of an individual’s life, which have consequences for the adjustment of theoretical models, the redesign of surveys, and the analysis of survey results (Pardo and Calvo, 2002; Cámara Hurtado and López Cerezo, 2012; Muñoz van den Eynde and Luján, 2014).

Such is the background for the present contribution. In this paper, our intention is to highlight the value of an element of scientific culture which, in our opinion, deserves much more attention in this field, namely the role of risk perception and critical attitudes (“risk culture”) in processes of social appropriation of science. In our view, risk culture has been inadequately conceptualized and inappropriately measured in current models of scientific culture generally used as a basis for drawing up surveys on public attitudes to science and supporting policies in the field of science communication. Along with these considerations, this paper presents a critical review of current practices of population profile segmentation, including the one-dimensional representation of perceived risks and benefits, and of the systematic underestimation of critical attitudes to the social impact of S&T.

Our bull's-eye comprises what we call "critical engagers", i.e., critically minded, socially responsible individuals who tend to engage in and give an opinion concerning S&T change, combining an overall optimistic attitude with the perception of significant threats in particular fields of application. We will attempt to highlight the academic interest and political value of this type of citizen, attributing to this segment of the population a mature and intelligent stance which may well be employed in enhancing the relationship relations between science and society. Our study focuses on data provided by Spanish surveys on the public perception of science promoted by the Spanish Foundation for Science and Technology (FECYT, in the Spanish acronym), particularly the 2014 survey published in FECYT (2015).[1]

FECYT SPANISH SURVEYS: STATING THE PROBLEM

A common result of surveys on public attitudes to science is the identification of a population profile in the subsequent cluster analysis, namely "pro-science individuals", in addition to the use of the percentage incidence of this population segment to measure the degree of support for science by society. This is particularly the case in Spanish surveys on the public perception of science undertaken since 2002 by FECYT, in which "enthusiastic" and "moderate" pro-science individuals are prevalent. The labels "enthusiastic pro-science individuals" and "moderate pro-science individuals" have

[1] FECYT is a public institution presently under the authority of the Spanish Ministry for Economy and Competitiveness.

subsequently been used in biennial surveys on public attitudes to science in Spain by FECYT up to the present day with some changes in the name of the profiles and the selected variables forming the basis of cluster analysis.[2]

A cause for rejoicing is that pro-science individuals are a population segment that has been clearly increasing in Spain over the last decade, as detected in FECYT surveys through variables such as level of interest in science, level of consumption of scientific information, and the attribution of risks and benefits to S&T. Actually, one of the main variables used in the definition of this population segment is an optimistic perception of benefits/risks regarding the social effects of S&T. If we follow the recent evolution of the replies to the question about the benefits and negative effects of S&T in FECYT surveys, we can appreciate that a roughly continuous increase in optimism and favorable attitudes has taken place over the last 10 years. This has occurred parallel to an increasing level of interest in science, an increasing self-valuation of the level of scientific schooling, and an intensification of other variables normally related to closeness to science (Bauer and Howard, 2013; BBVA, 2012; Muñoz van den Eynde, 2013).

When assessing the results of these analyses, however, a number of issues need addressing. First, the aforementioned changes in the selected variables for measuring closeness or distance to science forming the basis of cluster analysis may have had an inadvertent effect on the results of the statistical analysis and be the cause of some

[2] With regard to this last issue, the only variables that are always present in the analysis are: level of interest in a wide array of subjects (food and consumption; S&T; films, art, and culture; sports; economy and business; medicine and health; the environment and ecology; politics; news about celebrities), level of information regarding these subjects, and the balance between positive and negative aspects of S&T.

strong fluctuations in the percentage size of clusters between biennial results (Cámara Hurtado and López Cerezo, 2015).

Second, evidence has been found of a lack of association in the responses provided by respondents to the questions of population-based surveys of the public perception of science (e.g., Pardo and Calvo, 2002; Muñoz van den Eynde and Luján, 2014). These findings have been attributed to the fact that the items included in the questionnaires have not been subject to analysis aimed at assessing whether they measure what they are supposedly measuring (Pardo and Calvo, 2002). They have also been attributed to the surveys' difficulties in discriminating between group of citizens in the population in terms of their perception of science (Muñoz van den Eynde and Luján, 2014).

Third, public opinion surveys share two premises that may also be contributing to the identified lack of association. On the one hand, it is assumed that human beings are rational and offer all their replies and judgements after pondering them thoroughly and in detail, and, on the other, it is assumed that every citizen has an opinion about every subject that could be of interest for social researchers and is ready to express it in the instant an interviewer knocks at their door. However, there is wide-ranging evidence against both premises (e.g., Tourangeau et al., 2000; Sturgis and Smith, 2010; Kahneman, 2011).

Finally, the variables for measuring pro-science attitudes have a very limited capacity for detecting those well-informed citizens who assign high benefits to science while at the same time showing a critical awareness of its effects, i.e., those considered in this paper as critical engagers, who must be clearly distinguished from "moderate pro-science” individuals according to FECYT Spanish surveys. Our main concern is regarding the balance question, which has been used as a key segmentation question in order to assess, in an aggregated way, the attribution of the benefits and risks of S&T along the lines of previous surveys (e.g., Eurobarometers 55.2, 224). The results offered by this variable are clear: all the editions of the FECYT survey show a steady increase in the percentage of people attributing more benefits than risks to S&T (from 47% in 2002 to nearly 60% in 2014), and a decrease in the percentage of people who think that both are balanced (from 32% to 26%), and that the risks are greater than the benefits (from 10% to 5%). These surveys likewise show a steady increase in the number of people who either do not answer or state that they have not formed an opinion regarding the issue (from 11% to 9%).

The problem concerns the variable itself, and particularly the assumption of the existence of a unique dimension to order both attributes. J. Miller points out (2004: 285) that although they tend to negatively correlate in the USA population, the perception of risks and the perception of benefits are not two poles of the same continuum, but rather two separate dimensions.[3] As highlighted in the specialized literature on risk perception (Slovic, 2000: 86-87, 139 ff., 146), even though there is a logical negative correlation between the perception of risks and the perception of benefits regarding particular substances and technologies, S&T delimit an extremely broad and diverse territory to detect up a single value along a unique continuum. The attribution to S&T of a high potential to contribute to social progress in health, agriculture or trade does not mean

[3] Miller’s cautions go back to at least 1997, in the collective study by Miller, Pardo and Niwa (1998): according to the aggregate results of this study for the association between perception of benefits and wariness about the impact of S&T, the USA and Canada show a moderately strong negative correlation of – 0.6; while Europe shows a weaker negative correlation of – 0.11.

that the individual does not recognize the risks or harmful effects of certain technological applications or industrial developments based on science, and vice versa.[4] Both form part of the complex reality of science in the modern world. Furthermore, as shown by research on social psychology and risk perception, both strong positive and negative attitudes regarding a complex topic may be held at one and the same time (Seidl et al. 2013, Binder et al. 2012: 844).[5]

Actually, the above considerations were taken into account when designing the FECYT-RICYT-OEI Ibero-American Survey of public attitudes, scientific culture, and public participation in S&T, undertaken in 7 major Ibero-American cities (FECYT-RICYT-OEI, 2009),[6] in which the authors collaborated both in its design and the subsequent analysis of results. Here, the traditional question regarding the balance between benefits and risks was disaggregated into two individual questions addressing the issues of benefits and risks. The salient fact was that, in all cases, the corresponding results were percentage sums above 100% in the perception of very-many plus many risks *and* very-many plus many benefits. Moreover, the corresponding results for the perception of very-many risks *and* very-many benefits provided percentage results above 100% in one

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[4] Besides, lay valuation and acceptability of risks is not only influenced by the perception of potential threats and benefits, but also by a variety of variables such as voluntariness, familiarity, control, available knowledge, catastrophic potential, severity of consequences, and immediacy of effect (ibid.).

[5] Seidl et al. (2013) argue for and exemplify the need to study the perception of risks and benefits independently, pointing out the academic interest and political relevance of highlighting bivalent and indifferent populations (with high and low scores, respectively, in both attributes).

[6] This was promoted by the Spanish FECYT, the Ibero-American Organization of States (OEI, in the Spanish acronym) and the Network of Indicators for Science and Technology (RICYT, in the Spanish acronym) with headquarters in Buenos Aires. The survey was conducted in autumn/winter 2007, in seven major cities in Ibero-America: Bogota, Buenos Aires, Caracas, Madrid, Panama City, Santiago, and Sao Paulo. A total of 7739 surveys were conducted in the 7 cities, in all cases with a sampling error of ±3% (FECYT-RICYT-OEI, 2009).

case (Bogota) and above 60% in all but one case (Caracas), thus showing that two different dimensions are involved here (Cámara Hurtado and López Cerezo, 2014).

AIMS OF THE STUDY

Based on the Spanish survey on the social perception of science undertaken in fall 2014 (FECYT, 2015), the primary aim of this paper is to provide evidence that a significant group of critical engagers, with certain interesting traits, exists in the Spanish population, a group largely overlooked by the traditional FECYT population profile segmentation by cluster analysis. These are conscious citizens who, while recognizing the risk and adverse effects of S&T development, maintain an overall optimistic attitude and high affinity to science, as well as a certain attitude of engagement which prevents inhibition and moves them to give their opinion on S&T issues. In our view, this population segment coincides partially with what Bauer (2009: 232) calls "loyal skeptics" and what the British PAS 2014 survey (Ipsos MORI, 2014) labels "distrustful engagers". A second, complementary aim of this paper is to contribute to a better understanding of what is known as "risk culture" (see above) as a valuable asset in processes of social appropriation of science in contemporary technological society (Bauer, 2008).

In order to identify our critical engagers group and, taking into account the aforementioned difficulties, a number of assumptions have been made:

1. The difficulties of public opinion surveys in identifying groups of Spanish citizens on the basis of their perception of science is at least partially due to the misconception that there is a unique perception of science in the population, one that is uniform and shared by all.

2. When faced with a public opinion survey, some respondents are better than others in their ability or their disposition to process the questions thoroughly.
3. Critical engagers are citizens interested in and informed about S&T. Their interest and level of information in other topical issues included in the survey is not relevant.

Bearing in mind these assumptions, this contribution pays special attention to identifying the target group described in the following section.

METHODOLOGY

Identification of the critical engagers group

We are searching for citizens who feel close to science in a non-naïve way: citizens with a fairly good level of interest in S&T and consumption, who have an overall optimistic attitude towards S&T, but who are also well aware of the risks and harmful effects in particular areas of S&T development. They are thus assumed to be able to identify the broad diversity of fields related to interaction between science and society. They are also assumed to be knowledgeable individuals who reject the blind enthusiasm summed up by the mythical view of science, though without rejecting science in itself. Under this light, instead of opting for the axiom of PUS or its contrary (the more you know, the less you like it), we understand that the more someone knows about science, the higher the probability of their being capable of expressing an opinion, especially critical opinions.

To operationalize this characterization, we selected the following questions and response options in order to capture the dimensions of optimism and support-to-science:

Q14. If you have to take stock of S&T bearing in mind all the positive and negative aspects, which of the following options presented below will better reflect your opinion?[7]

- *The benefits of S&T outweigh its harmful effects.*

Q18. In a context of fiscal retrenchment tell me, please, whether the different levels of government should invest more or less in research in S&T.

- *In favor for more investment by central government.*

To identify the critical dimension of the individuals we are seeking, two other selected questions are those expressed by the precautionary principle and its opposite phrasing. Thus, we selected those respondents who provided complementary responses to questions Q21E and Q21F, i.e., they disagree (totally disagree and tend to disagree) with Q21E and agree with Q21F (totally agree and tend to agree).

Q21: I'd like you to tell me if you totally disagree, tend to disagree, neither agree nor disagree, tend to agree, or totally agree with the following statements:

E. *It is wrong to impose restrictions on new technologies until it has been scientifically demonstrated that they can cause serious harm to humans and the environment.*

F. *While the consequences of a new technology are unknown, caution should be exercised and their use monitored to protect health and the environment.*

Therefore, the dependent variable is dichotomous, taking the value 1 for critical engagers (those that consider that the benefits of S&T outweigh its harmful effects, who

[7] Response options: The benefits of S&T outweigh its harmful effects; the benefits and harmful effects of S&T are balanced; the harmful effects of S&T outweigh its benefits; DK/NA.

are in favor of more investment by central government, who disagree with the idea that is wrong to impose restrictions on new technologies until their negative consequences have been demonstrated, and that agree with the precautionary principle), and the value 0 for the rest of the sample.

Control variables

Three variables were included to control for the adequacy of the criteria used to define the group of critical engagers. These are:

Q2B. I would now like to know whether you are not at all, slightly, somewhat, quite, or very interested in S&T.

Q3B. I would now like to know whether you are not at all, slightly, somewhat, quite or very informed about S&T.

Q.28. People can have different opinions about what is scientific and what is not. I am going read to you a list of subjects. For each of them, please tell me to what extent you think it is scientific (not at all, slightly, somewhat, quite, very):

- *Horoscopes (not at all).*

It is assumed that critical engagers will be more interested in and informed about science than the comparison group and that they will not associate horoscopes with science.

Independent variables

It is also assumed that critical engagers differ in their perception of science compared to other individuals in the sample. We included the following questions to test this hypothesis:

Q12. Do you think progress in S&T brings more advantages or disadvantages for…?

A. *Economic development*

B. *The quality of life in society*

C. *The safety and protection of human life*

D. *Conservation of the environment and nature*

E. *Coping with diseases and epidemics*

F. *Foodstuffs and agricultural production*

G. *The creation of new jobs*

H. *An increase in and enhancement of interpersonal relationships*

I. *An increase in individual liberties*

J. *A reduction in the gap between rich and poor countries*

Q15. Balance between the positive and negative effects of some applications of S&T. Same response options as in Q14:

A. *Cloning*

B. *Nuclear energy*

C. *Stem cell research*

D. *Fracking*

E. *The Internet*

F. *Mobile telephony*

G. *Wind turbines*

H. *Genetic disease diagnosis*

Q21. The degree of agreement with various statements (totally disagree; tend to disagree; neither agree nor disagree; tend to agree; totally agree):

A. *We cannot trust scientists to tell the truth about controversial issues because they are increasingly more dependent on funding from industry.*

B. *Researchers do not allow those who fund their work to influence the results of their research.*

C. *S&T can solve all problems.*

D. *There will always be things that science cannot explain.*

H. *Scientific knowledge is the best basis for drawing up laws and regulations.*

I. *In the drawing up of laws and regulations, values and attitudes are as important as scientific knowledge.*

J. *Decisions on S&T are best left in the hands of experts.*

K. *Citizens should play a more important role in decisions on S&T.*

Q.26. Trust in different institutions (very little, little, neither trust nor mistrust, quite a lot, a lot):

A. *Hospitals*

B. *Universities*

C. *Public research organizations*

D. *Political parties*

E. *The media*

F. *The Church*

G. *Associations (of consumers, ecologists, etc.)*

H. *Companies*

I. *Government and public administrations*

J. *S&T museums*

On the other hand, we assume that critical engagers are more knowledgeable about science and more accustomed to using scientific information in their daily lives. We accordingly assume that they will be more familiar with the different types of behavior that supposedly reflect appropriation of science (Q29) and that they will score better on the quiz test of scientific literacy (methods and content) included in the survey (Q30 and Q31, respectively). We also assume that they are more prone to giving their opinion to interviewers and, hence, we expect to find that they have left fewer questions unanswered.

Q.29. I will now read some phrases describing different types of behavior that people may manifest in their daily life. For each of them, please tell me whether it describes something you tend to do frequently, occasionally, or very rarely:

A. *Read the leaflets of medicines before using them.*

B. *Read food labels or be interested in food qualities.*

C. *Follow the technical specifications of appliances or instruction manuals.*

D. *Take into account a doctor's opinion when following a diet.*

Q30. Suppose a group of scientists is assessing the efficacy of a drug used to treat high blood pressure. I am now going to present you with four options to conduct that study. Which option will be the most useful for scientists to establish the efficacy of the drug?

1. *Ask the patients how they feel and see if they notice any effect.*
2. *Analyze each of the drug components separately.*
3. *Give the drug to some patients, but not to others and then compare what happens to each group.*
4. *Use their knowledge of medicine to establish the efficacy of the drug.*

We obtained three quantitative variables to test the above hypotheses:

- *Knowledge* is the sum of correct answers to question Q30 and the 13 items in Q31 (a standard quiz test on scientific literacy content),
- *Appropriation* is the sum of the responses to Q29, and

- *Number of Don't Know* is the sum of items left unanswered in the survey as a whole.

We also analyzed the possible differences between the critical engagers group and the rest of the sample due to sociodemographic variables: sex, age, and level of completed studies. Finally, we included in the analysis the other response options to the question about the balance between the benefits and risks of S&T to ensure that the critical engagers group is characterized only by the selected option.

Statistical Analysis

SPSS version 22 was used to analyze the data from the 2014 edition of the Spanish survey on the public perception of science conducted by FECYT.

As our aim is to identify the characteristics that differentiate the group of critical engagers from the overall sample, we split the file into two groups: critical engagers (target group) and the rest of the sample (comparison group). We obtained the frequency distribution of the categorical variables and the mean and standard deviation of the numerical variables for each group. We used the one-sample Chi-square test and the one-sample t-test to test whether the group of critical engagers differs from the overall sample in terms of the control, independent and sociodemographic variables.

We used discriminant analysis to identify the characteristics that best differentiate our target group from our comparison group. For this purpose, the techniques of choice are either discriminant analysis or logistic regression. The latter tends to be the technique most widely used for the reason that discriminant analysis needs to meet certain assumptions: multivariate normality of the independent variables and unknown (but equal) dispersion and covariance structures for the groups as defined by the dependent variable. However, mixed evidence exists concerning the sensitivity of the technique to violations of these assumptions. Data not meeting the assumption of multivariate normality can give rise to problems in the estimation of the discriminant function. Unequal covariance matrices can negatively affect the classification process (Hair et al., 1998). However, multivariate normality is not a problem with large samples, and ours is large enough (see below). The classification problem is even easier to resolve. This problem will affect the results if the two groups created as a function of the dependent variable differ in size. If this is the case, a simple random sample of the same size as the smaller group can be obtained from the larger group to test the adequacy of the classification.

Taking all the above into account, we opted for discriminant analysis for three main reasons. First, it is a very useful technique for understanding group differences. It helps to identify the characteristics that differentiate two groups and provides a function capable of distinguishing the members of one group from those of the other with the maximum precision. This technique not only provides information about the variables contributing to differentiating the groups, it also indicates how many variables are needed for the best possible classification. Second, as a classifying tool, it offers the possibility of validating the results thus obtained. Third, it is a statistical technique for reducing dimensionality, in which p independent variables are transformed into a single dimension that is a linear combination of the independent variables that contribute to differentiating the two groups (Haier et al., 1998). In contrast, logistic regression is a technique designed to *predict the probability* of an event occurring. In logistic regression, the predicted value must be bounded to fall within the range of zero and one. To do so, the technique uses an assumed relationship between the independent and dependent variables that resembles an S-shaped curve. This relationship between the variables requires a somewhat different approach in estimating, assessing the goodness of fit, and interpreting the coefficients (Hair et al., 1998). Therefore, we did not opt for logistic regression for two reasons. First, this technique is used for prediction, not for understanding. Second, the interpretation of the obtained coefficients is neither direct nor simple.

Discriminant analysis requires the independent variables to be numerical or they must, at least, admit meaningful numerical treatment. The variables included in the survey are supposedly ordinal and will fulfill the latter requirement. Nevertheless, some doubts arise about the ordinal nature of the response options to the questions about the balance between the benefits and risks of S&T (Q14), and its applications (Q15). That is to say, if it is assumed that the response to these questions is an indication of an attitude towards science, how can the options be ranked in order to reflect this attitude? Are individuals that say that the risks overcome the benefits showing a negative attitude? Do people who consider that the risks and benefits are balanced show a more negative attitude than those who consider the benefits to be greater than the risks? The results in Table 3 provide evidence confirming these doubts and therefore we decided to include these questions as dummy variables. This transformation gives numerical meaning to the variable, given that a dummy variable indicates that those with a 1 opted for the corresponding response option, while those with a 0 did not. We accordingly included four dummy variables for each item in Q15. Moreover, we included three additional dummy variables to incorporate the response options in Q14 that did not contribute to identifying our target group.

RESULTS

From the overall sample of 6354 respondents, 3784 (59.5%) agree that the benefits of S&T are higher than their risks, while 2570 (40.5%) disagree. There are 1282 people for whom Government should not increase S&T funding (40.5%), but 3784 (59.5%) consider this increase to be necessary. There are 2389 respondents (37.6%) who disagree with the idea that it is erroneous to impose restrictions on new technologies while it has not been scientifically proven that they can cause severe harm to humans or the environment, whereas 3965 (62.4%) agree with this statement. Finally, 1541 people (24.2%) disagree with the precautionary principle, while 4813 (75.8%) agree with it. When combining the four variables, we found that the group of critical engagers comprises 1239 people (Table 1). This group represents 19.56% of the surveyed population. This figure falls between the 16.1% of enthusiastic pro-science individuals and the 24.1% of moderate pro-science individuals, according to the 2014 FECYT cluster analysis. This makes it very likely that our target group, critical engagers, includes individuals from both clusters.

Table 2 shows the result of cross-tabulating the dependent variable with the control variables. We found statistical differences between the two groups that provide evidence in favor of our initial hypothesis. Hence, people from the critical engagers group are more interested in and informed about science compared to the rest of the sample. At the same time, although the perception that horoscopes are not scientific is widespread in the Spanish population, this opinion is even more prevalent in our target group. We have highlighted in bold type the cells reflecting the most significant differences between the two groups according to the Adjusted Standardized Residuals of the Crosstabs procedure in SPSS. These residuals indicate the cells that contribute significantly to the chi-square value. Hence, they do not show the cells with the highest frequency, but those that most contribute to the found differences.

Insert Table 1

Insert Table 2

As to the variables used to characterize the target group (Table 3), we found significant statistical differences between the two groups (critical engagers and the rest of the population) in almost all the variables. The only exception is the opinion about the role of scientific knowledge in the drawing up of laws and regulations (Q21G). When focusing on the opinion about the advantages or disadvantages of progress in S&T, Table 3 shows significant differences between the two groups in every item, all of which are in the same vein: the individuals in our target group are more prone to associate S&T change with advantages, while the rest of the sample is distinguished by the opposite trend.

Regarding the evaluation of the balance between the benefits and risks of some applications of S&T (Q15), the profile of responses of the two groups is quite different. The general sample seems to find it difficult to give an opinion about the issue and hence there are four items in which the most significant cell is the option “Don’t know” or “I do not have an opinion about the issue”. In the other five items, this comparison group of respondents chose the middle option: “benefits and damages are balanced”. In contrast, critical engagers tend to position themselves in relation to eight of the nine applications. They think that the risks are higher than the benefits in two cases: genetically modified foodstuffs and fracking. They also stand out for considering that the benefits of all the other applications are higher than their risks, with the exception of nuclear energy, where they adopt a balanced stance.

As to respondent opinions regarding different statements about S&T (Q21), we once again found that individuals from the general sample show a greater propensity to select the middle option (neither agree nor disagree) compared to critical engagers. Our target group is in disagreement with the idea that we cannot trust scientists because they depend on funding from industry (much more than our comparison group), and that S&T can solve everything (somewhat less than our comparison group). On the other hand, critical engagers think that researchers are independent from funders, that S&T can solve everything, that values and attitudes are as important as scientific knowledge for laws and regulations (much more than our comparison group), and that decisions on S&T are best left in the hands of experts (also in a significantly higher percentage). Moreover, 55% of critical engagers agree with the claim that citizens should play a more active role in relation to S&T decisions, although this percentage is very similar in the comparison group.

Insert Table 3

With respect to trust in different institutions, critical engagers show more trust in hospitals, universities, public research institutions, and S&T museums compared to the rest of the sample. This comparison group, in contrast, stands out once again for the frequency with which these individuals choose the middle option. The members of our target group also scores better in scientific literacy (Q30 and Q31), they show more types of behavior associated with the appropriation of science (Q29) and, as hypothesized, they leave less questions unanswered in comparison with the rest of the sample. Although statistically significant, these differences are nonetheless small. Finally, we found significant differences due to age and the level of completed studies, though not between males and females (Table 4).

Insert Table 4

The results of the discriminant analysis are shown in Table 5. Both the canonical correlation and Wilk's lambda contribute to quantifying the capacity of the independent variables to differentiate between our target group (critical engagers) and the comparison group. When the dependent variable (belonging to the group) is dichotomous, the canonical correlation is the simple correlation between the discriminant scores (the position on the line represented by the discriminant function) and a variable that has the value 1 or 0 depending on the group belonged to. Therefore, its magnitude can be assessed according to Cohen's criteria (Cohen, 1988). Thus, a canonical correlation of 0.516 reflects a large association between the variables and hence provides evidence in favor of the adequacy of the independent variables to discriminate critical engagers from the overall sample.

Wilk's lambda allows us to test the null hypothesis that the multivariate means of the groups (the centroids) are equal. The results provide evidence against the null hypothesis. Despite this finding, the value of Wilk's lambda is nevertheless high (0.733), which reflects the existence of a certain degree of overlap between the groups.

When the discriminant function is used to reclassify the subjects in order to assess the efficacy of the capacity to differentiate between the two groups, the results are only acceptable: 95.1% of the "others" group is correctly classified, but only 38.3% of the critical engagers are assigned to the corresponding group. Nevertheless, this result can be attributed to differences in the size of the groups. To test this hypothesis, we obtained a simple random sample the same size as the critical engagers group of subjects belonging to the comparison group. When doing so, 92% of critical engagers are correctly classified (this analysis is not shown).

Insert Table 5

DISCUSSION

The chosen variables used in the statistical analysis and their significant discrimination of a particular group of citizens with a certain degree of homogeneity allow us to point out a number of interesting features characterizing those individuals we have called critical engagers. These findings allow us to reflect in this section on the role and meaning of risk culture as part of the scientific culture of citizens.

Our starting point was to detect and better understand those individuals who are critically and socially responsible and are not reticent about expressing concern regarding scientific-technological change. Perhaps the most interesting feature highlighted by the study is that these are citizens with an opinion and who have enough knowledge and motivation to express it when required. They also enjoy some degree of personal engagement because “science matters” for these citizens, who thus tend to form and provide an opinion concerning the social effects of S&T, avoiding reticence. They tend to shun the middle option and the refuge of “Don’t Know”. Furthermore, while having a positive overall view of S&T, they do not hold a uniform opinion concerning the diverse fields of S&T. Genetically modified foodstuffs and fracking are perceived with greater suspicion than by other citizens; nuclear energy divides them as to its pros and contras; and the Internet, mobile telephony, wind turbines and stem-cell research are fields which enjoy clear support from our target population.

In contrast, the comparison group is characterized by a significantly higher inclination to opt for the “Don’t know” response and, above all, for choosing the middle option. The question of the usefulness and significance of the middle option in opinion polls is still a matter of debate in the literature. However, Sturgis et al. (Surgis and Smith, 2010; Sturgis, Roberts and Smith, 2014) have provided evidence that it is a response option resorted to by people who do not have a definite opinion on the subject, but do not want to admit it. We could say that the option of an intermediate response acts as a refuge option for those who do not have a clear opinion on the issue but who wish to show they have one, or who, not having such an opinion at all, do not want to seem to be shying away from responding to the survey.

As shown by our analytic variables, critical engagers have an overall positive attitude towards science and tend to accept the precautionary principle (while rejecting its contrary). They are also more interested in and more informed about S&T, at the same time as being more disinclined to consider horoscopes scientific. Furthermore, they achieve better scores in questions measuring scientific literacy, concerning both scientific methods and content. Although it has less weight, they disagree with the mythical view of science concerning the claim that science can solve any problem, which is likewise in line with our hypothesis. They are also found to disagree with the idea that "you cannot trust scientists due to their increasing dependence on private funding". Finally, this group especially trusts hospitals, universities, and public research institutions. In contrast, the comparison group (the general population) is characterized by opting for the middle option in most of the questions. They are also defined as leaving more questions unanswered and, as anticipated, by attributing more scientificity to horoscopes. In addition, they are more prone to rely on the media and Government than our target citizens.

As to the discriminant analysis, two important conclusions can be drawn. First, the results of analyzing data from population surveys improve somewhat when profiles are established within them. That is to say, there is no single perception of science in the Spanish population, but many. Second, and this an important limitation of this study, we have identified a group of critical engagers of relative "quality", because, as reflected in

Table 3, there are no major differences between the groups on important variables according to our hypotheses, such as the score on questions of literacy or the number of "Don't knows" plus no replies. We consider this limitation to be associated, at least partially, with the aforementioned difficulties of public perception of science surveys to discriminate between the different perceptions of science. Nevertheless, although our group is not ideal, the results lead us to believe that it distinguishes a particular type of citizen who can be clearly recognized among the Spanish population, leaving open the question of a better identification by means of different statistical tools.

CONCLUSIONS

Critical engagers constitute a population segment of academic interest for answering the question: What does it mean to have scientific culture? In our view, the population that has significantly assimilated scientific culture, i.e., those individuals who are interested in science and are regular consumers of scientific information, a circumstance that has an impact on their beliefs and behavior (detected by means of specific questions such as Q29 above), characteristically constitutes a population of critical engagers.

This is a critically-minded pro-science population, partly hidden beneath inadequate methodological designs and misleading labels for cluster analysis (such as "moderate pro-science individuals", which implies some kind of suboptimal status). It is very doubtful that we could dub an "enthusiastic" pro-science individual as more *pro-science* than critical engagers, particularly when the latter feel so interested in S&T, perceive science's contribution to the advancement of society, and generally support S&T as strongly as the former, though with the minor, yet crucial difference that critical engagers do not have a naïve perception of S&T and are not unaware of their risks and harmful effects, an aspect as socially relevant as their benefits.

Moreover, our results underpin the view that the attribution of risks and benefits cannot be represented as two polar values along a single continuum. We cannot simply associate a high perception of benefits with a high level of scientific culture (the axiom of PUS). Critical engagers constitute a meaningful percentage of the population and are characterized by a bivalent attitude towards S&T, thus combining the attribution of a high level of benefits while at the same time holding a certain negative perception of particular aspects of S&T, or at least some level of concern.

In our opinion, this result does not imply inconsistency, but rather shows a non-naïve perception of the complexity of the effects of S&T on health or the environment, as well as (meta-scientific) awareness of the limits and uncertainties of S&T[8] on the part of citizens who consider science to be something close and familiar to them. This bivalent population that gives high scores to the benefits of S&T, but is also aware of the risks, in addition to showing an articulate opinion towards controversial issues such as nuclear energy or genetically modified foodstuffs, in fact deserves further study via new methodological approaches.

Besides, critical engagers comprise a population with clear political interest. These are educated, critically-minded citizens who give their opinion and display information-seeking behavior. They enjoy some degree of personal engagement because “science matters” for these citizens, who thus tend to form and provide opinions concerning the social effects of S&T, avoiding reticence.[9] This thus constitute an argument for

[8] Sjöberg (2001) understates the relevance of (lack of) trust in explaining the perception of the risk involved in technological threats, emphasizing instead public awareness about scientific uncertainties and the unknown effects of modern technological systems as the main explanatory factors.

[9] As to the political value of what has been dubbed “critical trust” (reliance combined with healthy skepticism), see Poortinga and Pidgeon (2003).

promoting intelligent criticism at the service of a socially-sensitive science (Wynne, 2014), as well as a critical attitude in S&T education and communication.

It is often stated that trust, including the reliance on risk management, is a vital asset for the proper functioning of a society. It is certainly a key element of social capital in contemporary society, although another key element in participatory democracies is political accountability. In a world of rapid change due to the effects of S&T, with a variety of actors struggling for limited resources in the public arena, a certain amount of skepticism on the part of a critically-minded, yet engaged population is sign of a mature attitude that helps to optimize such functioning.

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Conflict of interest statement

The authors declare that there are no conflicts of interest.

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Table 1. Identification of the "critical engagers" group

The benefits of S&T outweigh their harmful	Government should increase S&T funding	Disagreement P21E: It is erroneous to impose restrictions	Total

effects				No	**Yes**	
No	No	Agreement P21F: While the consequences of a new technology are not well known...	No	249	19	268
			Yes	248	182	430
		Total		497	201	698
	Yes	Agreement P21F: While the consequences of a new technology are not well known...	No	445	70	515
			Yes	792	565	1357
		Total		1237	635	1872
	Total	Agreement P21F: While the consequences of a new technology are not well known...	No	694	89	783
			Yes	1040	747	1787
		Total		1734	836	2570
Yes	No	Agreement P21F: While the consequences of a new technology are not well known...	No	109	27	136
			Yes	263	185	448
		Total		372	212	584
	Yes	Agreement P21F: While the consequences of a new technology are not well known...	No	520	102	622
			Yes	1339	**1239**	2578
		Total		1859	1341	3200
	Total	Agreement P21F: While the consequences of a new technology are not well known...	No	629	129	758
			Yes	1602	1424	3026
		Total		2231	1553	3784
Total	No	Agreement P21F: While the consequences of a new technology are not well known...	No	358	46	404
			Yes	511	367	878
		Total		869	413	1282
	Yes	Agreement P21F: While the consequences of a new technology are not well known...	No	965	172	1137
			Yes	2131	1804	3935
		Total		3096	1976	5072
	Total	Agreement P21F: While the consequences of a new technology are not well known...	No	1323	218	1541
			Yes	2642	2171	4813
		Total		3965	2389	**6354**

Table 2. Results of cross-tabulating the dependent variable with the control variables

Variable		Critical engagers	Others	Test
		%	%	1-sample χ^2
Q1. Interested in S&T	Not at all	3.7	8.3	χ^2 = 100.54*, DF = 4
	A little	12.8	**18.1**	
	Somewhat	33	35.7	
	Quite a lot	**31.9**	22.4	
	Very much	18.7	15.5	
Q3. Informed about S&T	Not at all	7.4	13.4	χ^2 = 109.65*, DF = 4
	A little	17.4	**25.9**	
	Somewhat	**45.9**	36.9	
	Quite a lot	23.1	17.9	
	Very much	6.2	5.9	
Q28. Perception of the level of scientificity of different topics		**%**	**%**	**1-sample χ^2**
E: Horoscopes	Not at all	**82.4**	61.3	χ^2 = 225.70*, DF = 4
	A little	12.1	**21.9**	
	Somewhat	4	10.7	
	Quite a lot	0.9	4.2	
	Very much	0.6	1.9	

Table 3. Results of cross-tabulating the dependent variable with the independent variables

Variable		Critical engagers	Others	Test
Q12. Advantages or disadvantages of scientific and technological progress for…?				
		%	%	1-sample χ^2
A: Economic development	Advantages	93.7	84.3	χ^2 = 78.15*, DF = 1
	Disadvantages	6.3	15.7	
B: The quality of life in society	Advantages	91.3	86.2	χ^2 = 24.04*, DF = 1
	Disadvantages	8.7	13.8	
C: The safety and protection of human life	Advantages	87.3	81.7	χ^2 = 27.63*, DF = 1
	Disadvantages	12.7	18.3	
D: Conservation of the environment and nature	Advantages	73.2	65.9	χ^2 = 21.66*, DF = 1
	Disadvantages	26.8	34.1	
E: Coping with diseases and epidemics	Advantages	97.1	94.7	χ^2 = 13.23*, DF =
	Disadvantages	2.9	5.3	
F: Foodstuffs and agricultural production	Advantages	73.7	68.6	χ^2 = 12.84*, DF = 1
	Disadvantages	26.3	31.4	
G: The creation of new jobs	Advantages	80	66.3	χ^2 = 93.61*, DF = 1
	Disadvantages	20	33.7	
H: An increase in and enhancement of interpersonal relationships	Advantages	74.7	61.3	χ^2 = 85.41*, DF = 1
	Disadvantages	25.3	38.7	
I: An increase in individual liberties	Advantages	76.2	60.1	χ^2 = 125,46*,

	Disadvantages	23.8	39.9	DF = 1
J: A reduction in the differences gap between rich and poor countries	Advantages	54.5	46.2	χ^2 = 31,3*, DF = 1
	Disadvantages	45.5	53.8	
Q15. Balance between the benefits and risks of some specific applications of S&T				
		%	%	1-sample χ^2
A: Genetically modified foodstuffs	DK / No opinion	8.8	18.6	χ^2 = 131.16*, DF = 3
	The risks are higher than the benefits	50	39.9	
	The benefits and risks are balanced	21.8	24.8	
	The benefits are higher than the risks	19.4	16.8	
B: Cloning	DK / No opinion	10.5	20	χ^2 = 89.57*, DF = 3
	The risks are higher than the benefits	45.9	42.2	
	The benefits and risks are balanced	20.3	20.3	
	The benefits are higher than the risks	23.3	17.6	
C: Nuclear energy	DK / No opinion	4.9	10.1	χ^2 = 68.81*, DF = 3
	The risks are higher than the benefits	52	55.2	
	The benefits and risks are balanced	24.7	18.7	
	The benefits are higher than the risks	18.5	16	
D: Stem cell research	DK / No opinion	2.1	8.4	χ^2 = 257.80*, DF = 3
	The risks are higher than the benefits	1.4	5	
	The benefits and risks are balanced	4.9	15	
	The benefits are higher than the risks	91.5	71.7	
E: Fracking	DK / No opinion	45.6	60.9	χ^2 = 170.28*, DF = 3
	The risks are higher than the benefits	33.4	22.7	
	The benefits and risks are balanced	10.3	10.3	
	The benefits are higher than the risks	10.7	6.1	
F: The Internet	DK / No opinion	1.8	5.3	χ^2 = 241.65*, DF = 3
	The risks are higher than the benefits	1.8	5.5	
	The benefits and risks are balanced	13.3	27.5	
	The benefits are higher than the risks	83.2	61.6	
G: Mobile telephony	DK / No opinion	0.4	2.4	χ^2 = 190.27*, DF = 3
	Risks are higher than benefits	2.8	6.8	
	Benefits and risks are balanced	14.7	27.3	
	Benefits are higher than risks	82	63.5	
H: Wind turbines	DK / No opinion	1.7	5.3	χ^2 = 199.51*, DF = 3
	The risks are higher than the benefits	1.2	4.4	
	The benefits and risks are balanced	7.1	17.7	
	The benefits are higher than the risks	89.9	72.6	
I: Genetic disease diagnosis	DK / No opinion	1.6	5.6	χ^2 = 171.84*, DF = 3
	The risks are higher than the benefits	0.9	2.9	
	The benefits and risks are balanced	3.1	12.1	
	The benefits are higher than the risks	94.3	79.4	
Q21. Agreement or disagreement with different statements about S&T				
		%	%	1-sample χ^2
A: We cannot trust scientists because they depend on funding from industry	Disagree	44.2	25.7	χ^2 = 284.77*, DF = 2
	Neither agree nor disagree	14.4	32.7	
	Agree	41.4	41.6	
B: Researchers are independent from funders	Disagree	34.6	29.9	χ^2 = 150.15*, DF = 2
	Neither agree nor disagree	17.9	35.1	
	Agree	47.5	35	
C: S&T can solve all problems	Disagree	45.9	47.4	χ^2 = 13.57*, DF = 2
	Neither agree nor disagree	23.3	26.9	

Agree	30.8	25.7	
D:There will always be things that science cannot explain — Disagree	12.8	11	$\chi^2 = 6.42$*, DF = 2
Neither agree nor disagree	15.3	15.7	
Agree	71.8	73.3	
G: Scientific knowledge is the best basis for laws and regulations — Disagree	28	21	$\chi^2 = 0.127$, DF = 2
Neither agree nor disagree	39.6	35.8	
Agree	32.4	43.1	
H: Values and attitudes are as important as scientific knowledge for laws and regulations — Disagree	10.4	12.3	$\chi^2 = 40.28$*, DF = 2
Neither agree nor disagree	24.4	32.8	
Agree	65.2	55	
I: Decisions on S&T are best left to experts — Disagree	9.2	9.6	$\chi^2 = 79.96$*, DF = 2
Neither agree nor disagree	11.7	21.2	
Agree	79.1	69.2	
J: The active role of citizens in decisions about S&T — Disagree	26.3	14.8	$\chi^2 = 179.32$*, DF = 3
Neither agree nor disagree	18.2	29	
Agree	55.5	56.2	
Q26: Trust in different institutions			
	%	%	1-sample χ^2
A: Hospitals — Very little	0.8	1.8	$\chi^2 = 80.35$*, DF = 4
Little	2.7	5.2	
Neither trust nor mistrust	6.5	12.6	
Quite a lot	42.8	41.7	
A lot	47.2	38.7	
B: Universities — Very little	1.5	1	$\chi^2 = 61.57$*, DF = 4= 4
Little	2.1	4.5	
Neither trust nor mistrust	8.6	15.9	
Quite a lot	49.4	44.9	
A lot	38.4	33.7	
C: Public Research Institutions — Very little	1.9	3.9	$\chi^2 = 51.08$*, DF = 4
Little	6.9	7.7	
Neither trust nor mistrust	20.8	26.2	
Quite a lot	43.1	40.2	
A lot	27.3	22.1	
E: The Media — Very little	11.3	10.3	$\chi^2 = 66.44$*, DF = 4
Little	27.6	19.9	
Neither trust nor mistrust	42.6	42.5	
Quite	15.7	23.5	
A lot	2.7	3.8	
G: Consumer associations — Very little	4.3	9.1	$\chi^2 = 53.40$*, DF = 4
Little	12.5	16.2	
Neither trust nor mistrust	44.2	39.6	
Quite a lot	32.8	27.5	
A lot	6.3	7.5	
I: Government and Public Administration — Very little	44.5	35.3	$\chi^2 = 83.30$*, DF = 4
Little	29.2	29.4	
Neither trust nor mistrust	19.3	24.7	
Quite a lot	6.6	8.8	
A lot	0.4	1.8	

J: S&T Museums	Very little	1	2.8	χ^2 = 94.89*, DF = 4
	Little	2.7	3.6	
	Neither trust nor mistrust	13.7	23.6	
	Quite a lot	50.8	43.7	
	A lot	31.8	26.3	
		Mean (SD)	Mean (SD)	1-sample T
Knowledge (Sum of P.30 and P.31)		10.51 (2.17)	8.82 (2.63)	t = -5.95*
No. of Don't Knows		26.58 (9.03)	28.11 (10.4)	t = 6.80*
Appropriation of science (Sum of P29 items)		14.28 (2.79)	13.73 (3.06)	t = - 6*

*p< 0.05

Table 4. Results of cross-tabulating the dependent variable with the sociodemographic variables

Variable		Loyal sceptics	Others	Test
		%	%	1-sample χ^2
D:1 Sex	Male	48.7	48.3	$\chi^2 = 1.18$, DF = 1
	Female	51.3	51.7	
D.2: Age	From 15 to 24	17.9	16.4	$\chi^2 = 55.14^*$, DF = 5
	From 25 to 34	19.6	19.2	
	From 35 to 44	21.5	17.1	
	From 45 to 54	16.8	14.4	
	From 55 to 64	11.9	12.4	
	65 or older	12.4	20.5	
D. 8: Level of finished studies		%	%	1-sample χ^2
	Without studies	0.8	2.4	$\chi^2 = 273.33^*$, DF = 7
	Primary schooling not completed	0.4	3.5	
	First grade	8.5	16.2	
	Second grade to 14 years old	20.9	24.9	
	Second grade to 16 years old	31.1	33.5	
	First-cycle university degree	14	8.5	
	Second-cycle university degree	19.6	10.3	
	Third-cycle university degree	1.8	0.8	

*p< 0.05

Table 5. Results of the discriminant analysis

Critical engagers		Others	
Variable	Coefficient	Variable	Coefficient
Q12A. Advantages for economic development	-0.065	Q12B. Advantages for the quality of life in society	0.088
Q12G. Advantages for the creation of new jobs	-0.135	Q14. I do not have an opinion on the relationship between benefits and risks of S&T	0.237
Q12I. Advantages for an increase in and enhancement of interpersonal relationships	-0.097	Q14. The risks of S&T outweigh its benefits	0.300
Q15A. The risks of genetically modified foodstuffs outweigh their benefits	-0.113	Q14. The benefits and risks of S&T are balanced	0.623
Q15C. The benefits and risks of nuclear energy are balanced	-0.064	Q21G. Disagree with "scientific knowledge is the best basis for laws and regulation"	0.071
Q15E. The benefits of fracking outweigh its risks	-0.069	Q21A. Neither agree nor disagree with "we cannot trust scientists because they depend on funding from industry"	0.177
Q15F. The benefits of the Internet outweigh its risks	-0.086	Q21B. Neither agree nor disagree with "researchers are independent from funders"	0.123
Q15H. The benefits of wind turbines outweigh their risks	-0.111	Q21J. Neither agree nor disagree with "citizens have to play an active role in decisions about S&T"	0.090
Q21A. Disagree with "we cannot trust scientists because they depend on funding from industry"	-0.112	Q26E. Trust in the media	0.085
Q21C. Disagree with "S&T can solve all problems"	--0.096	Q26I. Trust in Government and Public Administration	0.061
Q21J. Disagree with "citizens have to play an active role in decisions about S&T"	-0.158	Q28E. Perception that horoscopes are scientific to some extent	0.177
Q21D. Neither agree nor disagree with "there will always be things that science cannot explain"	-0.079	Number of questions unanswered	0.093
Q26A. Trust in hospitals	-0.149		
Q26G. Trust in consumer associations	-0.131		
Scientific literacy	-0.233		
	Centroid: -1.169		Centroid: 0.311
			Canonical correlation = 0.516
			Wilk's lambda = 0.733; p< 0.01