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Ignacio Nemirovsky

Mónica Giuliano

Silvia Pérez

Sonia Concari

Aldo Sacerdoti

See next page for additional authors

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Ignacio Nemirovsky, Mónica Giuliano, Silvia Pérez, Sonia Concari, Aldo Sacerdoti, and Marcelo Alvarez

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Ignacio Nemirovsky ¹, Mónica Giuliano ¹, Silvia Pérez ¹
Sonia Concarì ², Aldo Sacerdoti ¹ and Marcelo Alvarez ¹.

¹Universidad Nacional de la Matanza. Argentina.

²Universidad Nacional del Litoral. Argentina.

Abstract: College students' conceptions about probability and accuracy were explored. Both qualitative and quantitative analyses were done by means of two tests applied at two different moments. We show the results referring to the beliefs and conceptions about probability, margin for error, accuracy, certainty, truth and validity. Previous misconceptions about science may cause difficulties in the interpretation of scientific models. So, to find out students' beliefs about science and technology, a Likert scale type test was made and presented to part of the sample. Although most of the people who answered the survey accredited the incidence of probability in the results of a physical experiment, they also gave it accuracy and truth values which are not inherent. It is also remarkable that only a very low percentage has a posture that is coherent with the scientific vision of the terms.

Keywords: student beliefs; probability; teaching and learning statistics

1. Introduction

Probabilistic models are more often used in different disciplinary fields. For this reason basic concepts of probability and data analysis stretch to be introduced at high school and in some cases also at elementary level. Although, as teachers, we observe that freshmen not always can clearly recognize a random phenomenon or an actual situation with possibilities of representation with a statistical model. Reality and knowledge perceptions implicate on the individuals different attitudes in front of the randomness concept then also facing the probability ideas. This has a strong influence on understanding, develop possibilities and statistical-mathematic models applications.

Several papers have shown that misconceptions and erroneous beliefs about science and technology bring about misinterpretations of scientific models (Aikenhead et al, 1987; Aikenhead et al, 1992; Azcárate et al, 1998). Students who start studying Engineering at Universidad Nacional de La Matanza (UNLaM) show very little scientific and technologic knowledge at the moment they enter the university. Quantitative and qualitative analyses were made in order to make a test with the results of the answers students gave in the test (Alvarez et al, 2004; Sacerdoti et al, 2004). We present the results concerning the students' conceptions and beliefs about probability, margin for error, accuracy, certainty, truth and validity.

With the release of "*Curriculum and Evaluation Standards for School Mathematics*" (NCTM, 1989), it is proposed that primary and secondary school students have to study

probability, and also explore situations actively, experimenting and simulating probability models. In Argentina the study of probability has been included on the curricula from General Basic Education (EGB) to Polimodal since the Federal Law of Education was passed. But as Batanero (2002) argues, most schools do not deal with statistics owing to the length of the syllabuses. Thus, students start university without the expected knowledge of the subject.

Another aspect Fischein (1975) pointed out is the exclusive deterministic nature that the mathematics curriculum has had up to some years ago, and the need to show students how to face facts more realistically: "In our contemporary world, scientific education cannot be merely reduced to a certain, deterministic interpretation of events. An efficient scientific culture demands an education in statistic and probabilistic thought". The same idea can be applied to the teaching of Physics, when there is an abuse of the explanation of deterministic models, such as Newton's, ignoring in many cases the uncertainty of experimental results and the differentiation between model and reality (Gilbert et al, 1998). On the other hand, the fact that some phenomena we want to model have results that depend on chance rather than on a deterministic nature, makes it necessary to use probabilistic models.

In the present study we show the results referring to the beliefs and conceptions about probability, margin for error, accuracy, certainty, truth and validity of engineering students at the Universidad Nacional de La Matanza (UNLaM) at Argentina.

2. Previous research

In a previous study (Sacerdoti et al, 2004, abstract only) to search for the students' conceptions about probability and accuracy a semi structured poll was submitted to a 60 UNLaM engineering student sample. No directions on the poll subject were given to the students. Based on Azcarate et al. (1998) we generated a tool from their proposed test adding some items that allow us to disclose "ways of saying".

Conceptions about random events and the meaning of the words certainty, accuracy, uncertainty and probability were analyzed. A portion of the questionnaire used in that work is shown in Appendix I. The first question concerns the randomness of different experiences (referring to chance, the occurrence timing, the physical phenomena, meteorological events and health). The second question refers about the type of knowledge that is possible to obtain on the above experiences given as options certainty, accuracy, margin of error and probability. The last question has open answers; it is requested to define the previous phonemes.

Among the main conclusions of the previous study we can quote that many students associate randomness with event timing. This is shown by connecting, with higher frequency, randomness to future events and with less frequency to past events.,

Other remarkable issue concern the approach to the events, making a difference among *chance*, *everyday life* and *scientific*. Students considered a higher degree of randomness in the events related to chance while in those events related to the weather, where the everyday life predominates, a more unlike and subjective opinions showed up.

Finally, in those events related to the scientific,--physical models of planetary or missile movement -- physics perceptions as a very accurate and in some cases exact science were found.

Answering the last question the polled students should show what is the meaning of certainty, accuracy, margin of error and probability. From the answers it is noticed the words association. Among the answers the following are remarked:

The term *probability* was mainly associated with different, possible, results (it will rain, it will not rain) but it is not connected with values obtained from measurements of a magnitude. Probabilistic quality and incidence of chance in the values are ignored. Instead the students

prefer to use “margin of error” that is related to “rank”, “approximation”, “uncertainty”, “not reliable”, “low knowledge”. These conceptions should be taken into account when teaching subjects as uncertainty or confidence gap.

The term accuracy is associated with “precision”, “unique solution” and “no errors”. Also the term certainty is associated with “safety”, “correctness”, “predictable”, “true” and “valid”. The students admit that some information are given “using probability terms” but it seems that the meaning is not clear to them. Intrinsic temporary nature of science knowledge is not recognized by the students, on the contrary they express that science must be true or looking for the truth. Some students’ beliefs do not agree with Díaz, E. (1997): “Science is temporary in two aspects: first, the fact that an observational enunciation reveals itself as true, does not authorize to declare that the law from which it was derived is also true. In a second sense, temporary quality is shown in the emergence of rival theories not generated because an empirical disproof but originated in a determination of the scientific community”.

Nine phrases were selected and worked out from the analysis of answers (Appendix II). These phrases were integrated in a Likert type scale. In a next stage the nine phrases were included in a more general scale allowing a treatment with the principal component analysis (PCA) methodology.

3. Methods

With the aim of building an instrument to find out beliefs and conceptions of students who could start studying Engineering at UNLaM, 103 phrases were chosen from a first test with open ended questions. Almost two hundred students were asked to mark their agreement with each of the open ended questions, in a 1 – 5 scale. The students were picked at random among those who started to study Physics I in careers in Engineering at UNLaM. In order to reduce the number of phrases and integrate them on a new multidimensional scale, principal component analysis (PCA) with Varimax rotation was used, thus allowing us to choose those phrases which showed the greatest variety of answers, associating those representing the same idea in the same component. Afterwards, these phrases were analyzed with the aim of looking for testees’ profiles. As for the application of PCA, validity requirements were verified: KMO (Kaiser-Meyer-Olkin measure of sample adequacy) and Bartlett test. The following conditions were observed to select the number of components (Hair et al, 1999). **a.** to choose the components corresponding to self-values higher than 1; **b.** to include in each component items with factor loadings higher than 0.4 and high communality; **c.** to admit the items which are theoretically coherent with the component in which it is found, and **d.** to consider the number of components necessary to explain a minimum percentage of 60% of the total difference.

Using these criteria, at the beginning 22 main components were obtained (Giuliano et al, 2005), among which three referred to the character of validity of scientific knowledge, including terms such as probability, margin for error, accuracy, certainty, truth value, validity in the context of science of a specific physical phenomenon. These three components grouped nine phrases from the original 103, and were used to analyse conceptions in the testees. The PCA methodology was also applied to the sub-group of nine phrases released from the first test and coherent results with the analysis of the test of 103 phrases were obtained (Giuliano et al, 2006).

4. Results

PCA was performed over the sub-group of the 9 phrases (see Appendix II), and three equivalent components were found which satisfactorily passed the requisites of validity. Each component explains more of the 17% of the total difference, and the whole explains 56%, moreover, each was interpreted in the light of the phrases they were made of. Table I shows the resulting components.

Component	Interpretation	% Var. Explicate
Comp 1	It is possible to know with a certain probability or margin for error the exact location of the place a missile will hit.	20.4
Comp 2	It is possible to know certainly and accurately the exact location of the place a missile will hit.	17.7
Comp 3	Affirmations of science cannot be defined as true nor be formulated as completely accurate.	17.5

Table I: Interpretation of the resulting components and % of the explained difference

The tipicity index was estimated for each one of these components, as an average of the phrases it was made of pondered by its factor loading. The typical quality of each component was considered in an ordinal way grouping the values in three equal intervals classified as disagreement, indifference and agreement. The results are shown in Figure 1.

Figure 1: Percentage of responses in agreement, disagreement and indifference in each component.

As can be seen in Figure 1, approximately half of the responses are in the indifference area for all three components. In component 1 a high percentage of agreement with the probabilistic idea can be seen, although most of them also agree with the idea of certainty, and this implies ambiguity in the

interpretation of the concepts. The equal distribution of agreement and disagreement in both components 2 and 3 should not be taken as similar interpretations seeing that with the method of building of the components their co-relationship is low. This implies that it is not the same testees who do not agree or disagree with both factors.

The combinations of answers within factors show diverse postures distributed among all possible combinations of these three components, showing that only 10% of the testees show a posture which is

scientifically adequate, i.e., agrees with components 1 and 3 and disagrees with 2. Nine % of the testees admits probability and certainty in scientific phenomena, i.e. agrees with component 1 and disagrees with component 3, while only 16% agrees with both components.

5. Discussion

It is worrying to note that students show diverse interpretations of terms such as probability and accuracy and that these do not coincide with the scientific meaning of the terms.

Half of the testees do not have definite postures regarding the phrases under discussion, what represents a high percentage considering their simplicity. This sample, taken among a group of students interested in studying Engineering, reveals a poor knowledge of the topics analysed. It is feared that major deficiencies may be found in students who have finished the secondary school and have different interests.

It is highly important in our role of teachers at the basic level of engineering to acknowledge the deficiencies our students may have in order to help them to improve, taking into account that similar words may carry different meaning to teachers and students. The teaching of physics at any level should take into account modeling and probability. It is advisable to do activities which aim at surpassing ingenuous beliefs about deterministic models apart from including probabilistic models as from pre-university levels, not only in Maths but also in Physics.

Present results allow us to think about meaningful aspects of the students integral training. It is important that they develop an ability to recognize that there are different ways of reality modeling; among them the probabilistic and determinist models are relevant. Science looks for results prediction but cannot obtain exact values, however the probability concept should not be assigned to the phenomenon but to the information amount that can be obtained.

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Appendix I

- 1) Have the following experiences a random behavior? Why?
 - a) A seed germination
 - b) A number obtained from throwing a dice.
 - c) To guess correctly the number of a thrown dice that you cannot see.
 - d) Number of right sides obtained with 100 coin throws.
 - e) On November 5, 1933 it was raining in Buenos Aires.
 - f) Tomorrow it will rain in Buenos Aires.
 - g) In a month it will rain in Buenos Aires.
 - h) The place where Mars will be on Nov. 15, 2005.
 - i) The place where a missile will hit.
 - j) On next winter you will catch a flu.
- 2) Mark with an X possible knowledge types associated with each experience:
Certainty
Accuracy
Margin of error
Probability
- 3) Write down what you understand for: certainty, accuracy, margin of error, probability.

Appendix II

- P1) Science can tell if something is valid or not.
- P2) Science assertions cannot be define as true.
- P3) Science cannot asserts anything with full certainty.
- P4) It is possible to know with certainty the place where a missile will hit.
- P5) It is possible to know with accuracy the place where a missile will hit
- P6) It is possible to know with certain margin of error the place where a missile will hit.
- P7) It is possible to know with certain probability the place here a missile will hit.
- P8) Scientific theories change according to discovering of errors.
- P9) Scientific theories change because others scientists can find errors, meet others colleagues and discuss its truthfulness.