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ORIGINAL

STEM Education as a Teaching Method for the Development of XXI Century Competencies

La Educación STEM como método de enseñanza para el desarrollo de Competencias del Siglo XXI

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ABSTRACT

This research was carried out at Don Bosco School in the department of Villavicencio, where the contribution of STEM education to the development of competencies and skills of 21st century citizens is observed, studied and evaluated. To this end, a curricular proposal based on interdisciplinarity is presented, applying Project-Based and Problem-Based Learning in the subjects of Science (Physics), Technology, and Mathematics with tenth-grade students. The results show the characterization of the students, the processes of curricular integration in knowledge and soft skills. It can be evidenced that, according to the pedagogical model of the institution, tenth-grade students have a social and humanistic thinking, in the sense that some of them were concerned about the social context and oriented towards solving problems in their environment. After reviewing the curricular planning documents, clear guidelines on the conceptual model of the institution are appreciated. However, it is necessary to diversify the technological component to train competent citizens with a view to a generation immersed in the 21st century.

Keywords: Curriculum; 21st Century Skills; Technology; STEM.

RESUMEN

Esta investigación se llevó a cabo en el Colegio Don Bosco del departamento de Villavicencio, con el propósito de observar, estudiar y evaluar el aporte de la educación STEM en el desarrollo de competencias y habilidades de los ciudadanos del siglo XXI. Para ello, se presenta una propuesta curricular sustentada en la interdisciplinariedad, aplicando el Aprendizaje Basado en Proyectos y en Problemas en las asignaturas de Ciencias (Física), Tecnología y Matemáticas con estudiantes de décimo grado. Los resultados muestran la caracterización de los estudiantes, los procesos de integración curricular en los saberes y las habilidades blandas. Se puede evidenciar que, de acuerdo con el modelo pedagógico de la institución, los estudiantes de décimo grado presentan un pensamiento social y humanista, en el sentido de que algunos de ellos estaban preocupados por el contexto social y orientados a resolver problemas en su entorno. Tras revisar los documentos de planificación curricular, se aprecian unos lineamientos claros sobre el modelo conceptual de la institución. Sin embargo, es necesario diversificar el componente tecnológico para formar ciudadanos competentes con miras a una generación inmersa en el siglo XXI.

Palabras clave: Currículo; Competencias del Siglo XXI; Tecnología; STEM.

INTRODUCTION

Ongoing debates about global education revolve around addressing the needs, interests, and desires of future citizens who are currently immersed in technology. This invention has played a leading role in the development of communication and knowledge management over the past century, creating ongoing tensions, especially in developing countries like Colombia, due to their diverse needs in areas such as education.[1,2,3]

These needs fall upon a society marked by stark contrasts and realities, urgently requiring the incorporation of new teaching-learning methods to diversify how 21st-century future citizens assimilate knowledge and apply it holistically in their daily lives.[4,5,6,7,8,9]

To achieve this, it is essential to understand that continuous technological changes will generate new ways of working and new forms of interactions around knowledge, and that the new workforce will require new skills to ensure forward-thinking citizens are equipped to solve problems within their changing realities, using innovation and creativity for their full development in society.[10,11,12]

This research aims to develop these skills through a methodology called STEM (Science, Technology, Engineering, & Mathematics) in English.

METHODS

A mixed-methods approach was employed for the development of the research. In the first stage, quantitative and qualitative data were collected and analyzed. It is important to note that the mixed-methods blending occurs when initial quantitative results inform the qualitative data collection.[13]

On the other hand, the research paradigm used was explanatory, as its nature was relevant for the development of the study.[13]

Population and Sample

The Don Bosco School in the city of Villavicencio, Meta department, was founded in 1977 and has 567 enrolled students (as of 2021) from pre-kindergarten to eleventh grade. The school comprises a total of 22 classes, with an A+ superior category. Currently, it ranks among the top three schools at the municipal level, according to the 2020 "Saber" test results.

The study sample consisted of sixteen (16) eleventh-grade students from the Don Bosco School in Villavicencio, enrolled in 2021, aged between 15 and 17 years. Among them, there were 4 male students and 12 female students. Additionally, socioeconomic strata of the population were considered in the sample selection.

Techniques and Procedures

This methodology aimed to describe the perception of tenth-grade students from the Don Bosco School in Villavicencio about 21st-century competencies and the ways they conceive living in the world, thinking, working tools, and working methods. The goal was to propose a teaching method that would enable them to adopt various STEM education technologies. The categories established by the United Nations Educational, Scientific, and Cultural Organization (UNESCO) and national (MEN) organizations for 21st-century citizen competencies were used as references. The objective was to identify qualities, understanding their depth and dimension, from the wealth of information, closely knowing students' perceptions about their education and how to enhance learning in the classroom, leading to a holistic analysis and interpretation. To achieve this goal, the quantitative method was used, specifically percentage-based, for treating the responses of the group taken as a sample in this research. The questionnaire questions were developed considering a pilot test. The questions were structured by affinity parameters, according to the dimension of the competencies to be measured.

RESULTS AND DISCUSSION

To identify these 21st-century competencies, three instruments were developed. The first was a field diary, in which the peculiarities of Physics, Mathematics, and Technology classes were observed; the second was a documentary analysis of these three subjects; and the third, a survey of students from the Don Bosco Educational Institution, based on the four dimensions established by UNESCO and the MEN, namely: ways of living in the world, ways of thinking, tools for working, and ways of working. It is imperative to emphasize that the response averages and their correlation with the principal components resulted in a statistical analysis that approached the needs of the sample population, in order to determine the current reality of the students of the institution and the projection that exists regarding 21st-century competencies.

As an essential part of this research, a field diary was kept, in which the general guidelines for teaching classes in the present day were sought; taking into account that within the Institutional Educational Project (PEI), a conceptual methodology is established, with master classes, where the teacher is the main actor in the conventional educational model.

Next, the findings recorded in the classroom observations are described, which will be done in parallel between the three subjects taken as a sample. According to the institution's "Conceptual" methodology, it is

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possible to identify, within the school's class planning, a "Sequence and didactics" guideline, composed of the following 6 moments: Framing, where the teacher recalls the rules of the class; motivation, where the teacher must mention the importance of what will be learned; enunciation, as a moment in which the teacher must remember the teachings that must be acquired to achieve the competence indicated by the thematic grid; modeling, or when the teacher provides the step-by-step process that the student must follow to acquire the competence; simulation, where the student must assess whether they understand and clarify doubts with the teacher; and finally, practice, as a time when the student must apply the acquired knowledge—individually or in groups—according to the teacher's guidance. Considering the recorded observations, it is evident that within this methodology, students are passive actors in the acquisition of knowledge, and the class structure remains within a traditional model that does not allow the student to actively participate in their learning, becoming instead a conventional memorization process, without significantly contributing to the development of 21st-century competencies.

In this study, a thorough documentary analysis was conducted on the curricular planning documents implemented in the institution, with the aim of verifying standards, performance levels, DBA, evidence, teachings, competencies, and their alignment with the institution's cross-cutting projects, specifically in the field of mathematics. It was found that the curriculum aligns with the standards set by the MEN, but could benefit from incorporating technological resources to facilitate the application of theoretical concepts taught by teachers. In the physics curriculum, compliance with MEN standards is evident, but there is a lack of technological tools integration that would enable students to practice the concepts learned in class, and the inclusion of such tools could enhance learning. Similarly, the technology curriculum meets guidelines but could benefit from a focus that adds value to the new 21st-century competencies.

In the third stage, a quantitative data analysis was carried out to contrast qualitative information obtained from the previous instruments. A non-probabilistic convenience sampling was used due to the small number of individuals and the exploratory nature of the study. Additionally, a descriptive observational action study with analytical intent, ambispective data collection, and cross-sectional (cross-sectional) measurement were conducted. For the univariate analysis, qualitative variables were expressed in absolute and relative frequencies (percentages) through frequency tables and bar charts. Continuous quantitative variables were subjected to normality tests (Shapiro-Wilk) and expressed as central tendency measures (mean and standard deviation) to verify normal distribution or as median and interquartile range if the distribution was abnormal; histograms were then created. For the bivariate analysis, given the quantitative nature of the data for each questionnaire domain, a "corrplot" correlation matrix was evaluated among all questions comprising each of the four 21st-century competency domains, calculating Spearman's correlation coefficient (Rho) and exploring Lin's correlation coefficient (Pc) due to the small sample size.

For the multivariate analysis, given the quantitative nature of the variables, a principal components analysis was employed to simplify each domain based on the respective contributions and cosines for each vector. As a result, the questionnaire was divided into four domains: ways of experiencing the world, ways of thinking, tools for working, and ways of working. The first dimension included questions 1 to 9, the second dimension questions 10 to 21, the third dimension questions 22 to 27, and the fourth dimension questions 28 to 33, as shown in table 2. A Likert scale was used for the response options, with 1 indicating disagreement and 5 indicating agreement, also allowing for measurements of 2, 3, and 4.

Table 1. Questions asked to the sample population

Ways of living the world	When you relate the recreational aspect of your life, what actions do you think about?
	Is it important for you to know about gender equity and diversity?
	What do you know about climate change?
	How important is it for you to respect public resources?
	What do you think about this statement "Mine right ends when the other's begins"?
	What do you think about animal protection?
	Do you consider it important to study a professional career?
	Have you heard or do you know about the competencies of the 21st Century?
	Which of the following best describes your future projection?
Ways of thinking	Do you consider yourself creative?
	Do you visualize different solutions to a problem?
	Have you ever designed or built something?

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	Do you like to read?
	How do you learn best?
	Why is the sky blue?
	What do you think about the national strike?
	The clock shows 3:15. What is the angle between the hour hand and the minute hand?
	If you were president of Colombia, how would you reduce social unrest?
	If a friend of yours were to convulse at this moment, what would you do to help him/her?
	If 100 % virtual education came back, what would you propose to improve it according to your experience as a student?
Tools to work with	Which of the following programs do you know how to use?
	How do you use social networks?
	Do you know what gamification is?
	What features should a good data storage device have?
	When you need to consult information, where do you look?
	Do you know what programming is?
Ways to manage knowledge	What techniques do you use to improve your speaking skills?
	What techniques do you use to improve your non-verbal speaking skills?
	What percentage of English proficiency do you consider you have?
	Do you prefer to work individually or in a group?
	What characteristics should be present in teamwork?
	How should a team be organized to get results?

Once the information was obtained, the interpretation of each of the dimensions described above was carried out to observe the preponderance of the responses of the sample population (table 2).

Table 2. Average responses in the four dimensions evaluated

Questions	Median	RIC
1	1	0,75
2	5	0
3	4	0
4	5	0
5	5	0
6	4	2
7	4	1
8	3	0
9	4	2
10	3	2
11	3	1
12	3	1
13	3	1
14	4	1
15	5	2,5
16	3,5	2
17	5	0,25
18	3	2
19	5	0
20	2	3
21	5	0
22	2	2
23	4	0,25
24	2	1
25	3	2
26	5	0

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27	5	2,5
28	3	2
29	3	2,5
30	3	2
31	3	0,5
32	5	0
33	4	1

According to the average responses, it can be observed that the questions scoring highest in the "Ways of Living the World" dimension were: Question 2. Is it important for you to know about gender equity and diversity?, Question 4. How important is it for you to respect public resources?, and Question 5. What do you think of this statement, "My right ends when another's begins"? These results reflect the importance students assign to respect and the role people play in society as part of how they experience the world. In regards to Question 1. When you think about the recreational aspect of your life, what actions come to mind?, the majority answered "Traveling", which could be oriented towards globalization and a more integrated view of well-being in pursuit of life projects, where mobility experiences provide greater social knowledge.

Concerning the analysis of the results of the questions surrounding 21st-century competencies, when evaluating the second domain—"Ways of Thinking"—it was evident that questions 10 through 21 scored the highest. Specifically, Question 15. How do you learn best?, Question 17. What is your opinion on the national strike?, Question 19. If you were the President of Colombia, how would you reduce social discontent?, and Question 21. If education returns to 100 % virtual, what would you propose to improve it based on your experience as a student? This data points towards critical thinking, where individuals are clearly immersed in a context they would like to participate in, with the option to propose ideas based on their experiences and needs.

In another line of thought, the analysis of the "Tools for Working" dimension, which included questions 22 through 27, those that scored the highest were number 26. When you need to search for information, where do you look? and 27. Do you know what programming is? This allowed us to infer that the main source of information for the sample population was the "Google" search engine. Not to mention that this question allows us to discern a high interest in programming-related topics, which was met with a lack of theoretical and practical knowledge.

Lastly, the domain referring to "Ways of Managing Knowledge", from question 28 to 33, those with the highest scores were: Question 32. What characteristics should be present in teamwork? and Question 33. How should a team be organized to achieve results? From these, a strong preference among students for collaborative work was visible, with the majority choosing teamwork to achieve objectives, in other words, showing less preference for individual work.

Once the response averages were analyzed, the four dimensions under study in this research were graphed independently to provide a general overview of the correlation between the questions (figure 1).

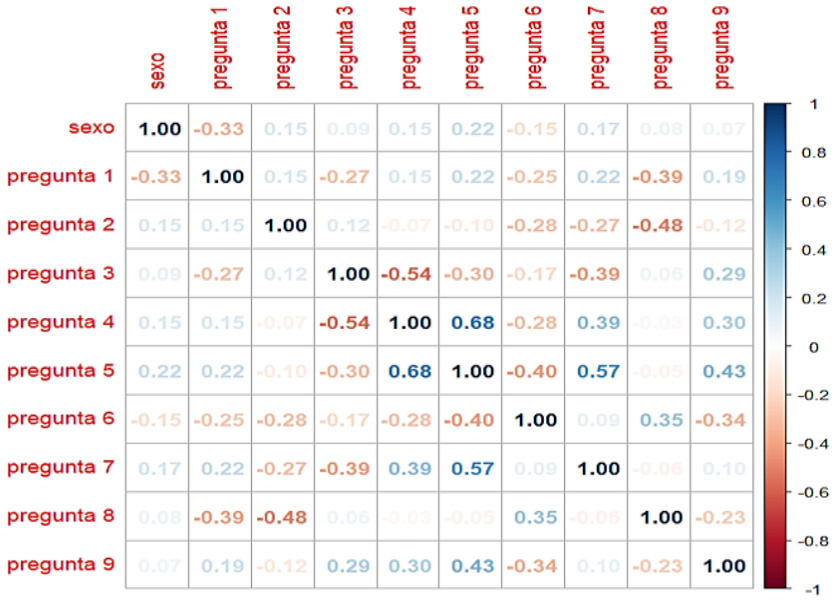

Figure 1. "Ways of living the world" dimension Correlation between questions 1 and 9

In the previous figure, we can observe certain ways of experiencing the world. When conducting a "bivariate" analysis between the questions that comprise this competency, a moderately significant correlation was evidenced between question 4. How important is it for you to respect public resources? and question 5. What do you think about this statement: "My right ends where another's begins"? (Rho=0,68, p=<0,001 Lin(Pc) 0,63).

Additionally, these same two questions were the ones that contributed the most to the domain, resulting in a significant impact on the sample population, where it can also be appreciated that values, common good, and respect for others are very important to the students. This is not an insignificant detail, from which it can be acknowledged that this 21st-century competency is being properly addressed by the institution, as its Educational Institution Project (PEI) considers values as a basic principle (figure 2).

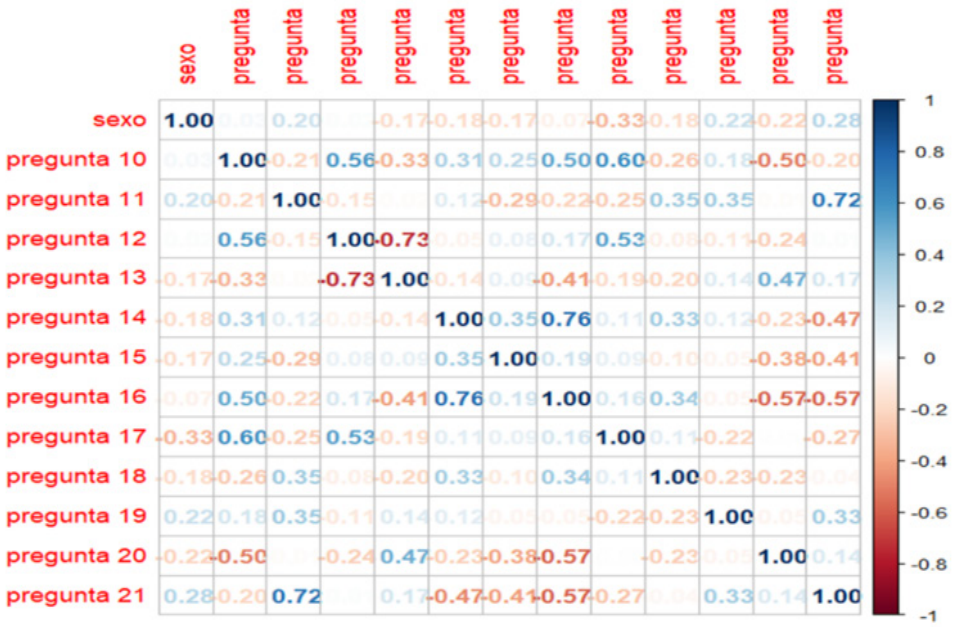

Figure 2. "Ways of thinking" dimension Correlation between questions 10 and 21

In the preceding figure, when analyzing the questions that make up this dimension, a significant association between questions 11 and 21 was observed (Rho=0,71 p=<0,01). Both questions might be measuring the same problem-solving capability. Nonetheless, questions 14 and 16 have a high relationship (Rho=0,75 p=<0,01).

In turn, questions 12 and 13 (Rho=0,73 p=<0,01) reveal that students still lack the ability to solve problems; this skill should begin to be developed within the institution's curriculum to bridge theory and practice and, additionally, confront students with real-life contexts, allowing for the assessment of their responsiveness to certain situations (Figure 3).

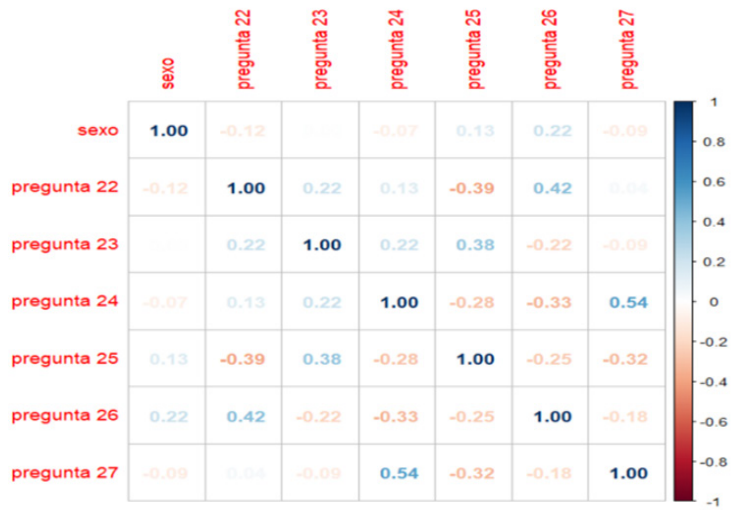

Figure 3. Dimension "Tools for work" Correlation between question 22 and 27

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Upon conducting a correlation analysis between the questions, a relationship was found between question 24, "Do you know what gamification is?" and question 27, "Do you know what programming is?" (Rho=0,54, p=<0,02, Ln(PC)=0,019). This showed a stronger contribution in relation to domain 1 in the principal component analysis. According to the responses collected from the sample population, there is a high interest in experiencing more hands-on education as opposed to theoretical, or a combination of both methodologies. This approach would allow for better engagement with new competencies in computational thinking and information management through technology. In light of these findings, the research suggests adopting STEM education as a method for introducing students to new tools both inside and outside the classroom (Figure 4).

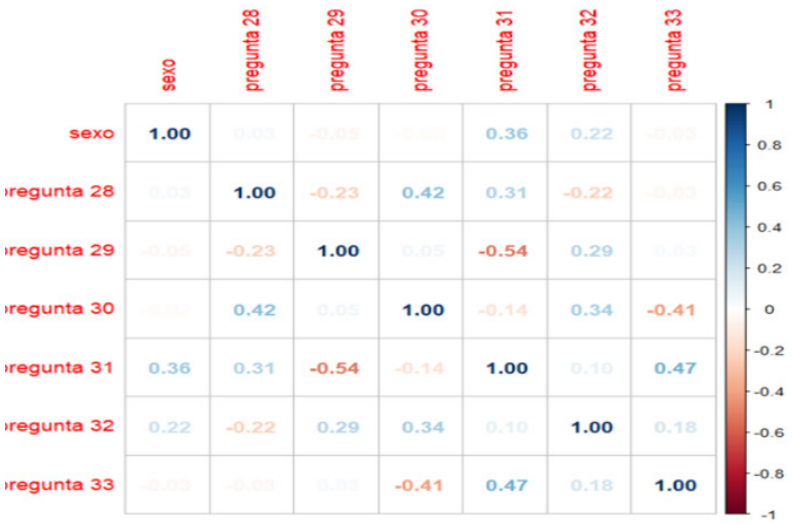

Figure 4. Dimension "Ways of managing knowledge" Correlation between question 28 and 33

A negative correlation was observed between question 29: "What techniques do you use to improve your non-verbal expression skills?" and question 31: "Do you prefer to work individually or in a group?" (Rho= -0,54, p=0,03). Upon analyzing this dimension, a prevalent insecurity emerged within the sample population, where students do not feel a solid practical foundation when speaking in public. Consequently, they feel more secure when working as a team, enabling them to combine the efforts of all group members to achieve academic goals.

This article is the result of a research project in which, as a discussion, the fulfillment of the research objectives is evidenced, starting with the general objective and continuing sequentially with the specific objectives. The research revolves around "Designing a curricular proposal that allows the integration of 21st-century competencies into the tenth-grade curriculum at Colegio Don Bosco in Villavicencio."

Initially, as outlined in the objective, the proposed design is based on the structure and documentary analysis of the institution, without affecting or interfering with the current planning. It serves as a starting point for establishing a cross-cutting project within the institution through the integration of three subjects deemed relevant for STEM education, with a primary focus on guiding 21st-century citizens' competencies.[14,15,16,17,18]

On the other hand, during the investigative process and information collection, repetitive evidence emerged as a result of the thorough analysis contributed by the bibliographic review of STEM education.[19,20,21,22,23,24]

This collection focuses on areas of opportunity and integration of programming, robotics, and applied technology, where engineering becomes cross-disciplinary within this model, fostering student attitudes through the scientific method as a fundamental tool for obtaining meaningful learning by combining theory and practice.[25]

Methodologically, the proposal not only meets the general objective but also presents content and international reference frameworks that can be adapted to the traditional conceptual model for obtaining creative results when problem-solving and working cooperatively, aiming at understanding statements and data, reflecting and adjusting the institution's model.

CONCLUSIONS

After reviewing the literature and contrasting the results of this research, it can be determined that in order to include a STEM education model in Don Bosco College, it is necessary to emphasize the management of technology and data processing as relevant resources. This would be achieved through the collection of data and the application of different computer tools in selected subjects such as physics, mathematics, and technology. It is also important to address the concerns raised by students regarding new ways of developing

practical learning. During the information gathering process, the interest of students in programming and collaborative work was appreciated.

It was evident that, according to the institution's pedagogical model, tenth-grade students exhibit a social and humanistic thinking, in the sense that some of them were concerned about the social context and were oriented towards solving problems in their environment. After reviewing the curricular planning documents, clear guidelines on the institution's conceptual model were appreciated, but it is necessary to diversify the technological component to train competent citizens for a generation immersed in the 21st century.

Finally, the subjects under investigation were observed, concluding that they have a clear methodology. However, it is necessary to train teachers in new digital technologies for the transversal application of the STEM model.

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FINANCING

Ninguna.

CONFLICTS OF INTEREST

No existen.

AUTHORSHIP CONTRIBUTION

Conceptualization: Ricardo Javier Albarracín Vanoy.
Methodology: Ricardo Javier Albarracín Vanoy.
Software: Ricardo Javier Albarracín Vanoy.
Research: Ricardo Javier Albarracín Vanoy.
Original writing: Ricardo Javier Albarracín Vanoy.
Writing-revision and editing: Ricardo Javier Albarracín Vanoy.