INTRODUCTION

The traditional teacher-centered educational model is still the main model used in schools, and science is taught accordingly (1). The way in which teachers present content to the students influences their understanding. Therefore, using resources based on their interests can promote and improve learning (2). In this context, alternative resources in science education have been implemented, including educational projects focused on the interests of the children (3, 4), science corners (5), music (6, 7), interactive platforms (8, 9), comics (10–14), and certainly many more.

Comics have proven to be effective in engaging and shaping student attitudes toward science in a positive way, facilitating their learning and improving their understanding (15). They are an excellent resource to deliver a substantial amount of information in a short, appropriate and effective way. With their narrative and images, comics facilitate learning, stimulate the imagination, and favor the development of logical thinking (16). There are a few examples of comics for science teaching (10, 15, 17), but their quantitative effect on knowledge acquisition remains largely unexplored (18). Most science educational comics are short strips and single-framed concept cartoons (19–22), are intended for English speakers, and are not freely available (23). Science communication with comics is scarcely even addressed in Latin America. The few existing reports come from Brazil and Mexico, and only in the latter were they written in Spanish (24) the second-most spoken language worldwide (25).
Therefore, we decided it would be a significant contribution to generate a comic book for Spanish-speaking populations.

Education in microbiology receives less attention than other science disciplines, so children are unfamiliar with the subject. In all likelihood, they will grab whatever information they find to build their knowledge about the microbial world (26). That information mainly comes from mass media (27, 28), with a not-so-positive image of microorganisms. Furthermore, microbiology poses a huge additional difficulty for educators: to explain an invisible world, to explain the unseen. To the best of our knowledge, the use of comic books in microbiology communication has only been explored in the book Microbes (29).

Here, we present a microbiology comic book created by experts in the field and adapted by experienced illustrator-scriptwriters as an educational resource to help educators teach microbiology and to aid in debunking preconceptions about microorganisms. Our book is an innovative tool, as it is a sequential, character-driven story, the graphics are excellent and attractive, it offers extensive coverage of themes, and it is freely available on the web and can therefore be used by others. To the best of our knowledge, there is no microbiology comic with such characteristics, even in English. Even though the content is adapted to the Uruguayan school curriculum for fourth to sixth graders (10–12 years old), it can be used with children of all ages, as the themes can be approached from different perspectives and in varying depths. The comic was recently released, and therefore its impact on the learning of microbiology has not been assessed. With this article, we hope educators will adopt the comic as an educational resource so it can be used and evaluated worldwide.

**PROCEDURE**

The comic was developed by a team of microbiology experts from the Institute of Biological Research Clemente Estable and scriptwriters and illustrators from Bandas Educativas (30). The comic is licensed under Creative Commons, non-commercial attribution, no derivatives (CC BY-NC-ND) and can therefore be used by downloading it from www.comicbacterias.com/comic/. As we intend to spread its use as an educational resource, we generated an English version of the script that can be found in the supplementary materials (Appendix 1). The story is articulated into four chapters spanning different themes, which we summarize here, providing examples of the content that can be addressed with each chapter.

**Chapter I: Introduction**

In this chapter, the reader is introduced to the existence of a microbial world in sequential storytelling, which works particularly well for comics. It introduces Bacteria through two main characters, Coco and Fran, who live in “Bacteritown,” situated in a coffee table. This introduction leads the reader to realize that the micro and macro worlds coexist (Fig. 1).

“The Great Disinfection” is announced as a metaphor for an ancient catastrophic event, playing a central role in the entire story. With graphical narrative, it is shown as an event that destroyed 99.9% of the bacteria population. This event was intentionally included for the reader to associate with the disinfectant propaganda.

Themes that can be addressed in this chapter include 1) bacteria diversity: phenotypes (i.e., Coco is a coccus and Fran is a bacillus) and functions (the different roles of the characters can be extrapolated to different functions in their niche); 2) the coexistence of macro and micro worlds.

**Chapters II, III, and IV: The Journey**

During the journey, the characters will visit different places, including the human gut, water, and soil (chapters II, III, and IV, respectively). This journey allows the reader to understand that there is a microbial world in every imaginable niche, including our own body. It also shows bacteria performing many important functions, which could be used to demystify the well-established popular concept that bacteria are only harmful. One main topic we wanted to address was the use and abuse of antibiotics, which is an alarming problem worldwide. How bacteria acquire resistance is covered in detail using sequential storytelling (Fig. 2). Themes that can be addressed in chapter II include 1) the microbiota and its role in decomposing food, producing nutrients, and training our immune system; 2) antibiotics and their effect on the microbiota; antibiotic resistance, DNA, and horizontal gene transfer.

Themes that can be addressed in chapters III and IV include 1) cyanobacteria and oxygenic photosynthesis, the trophic chain (autotrophy and heterotrophy), eutrophication, reproduction in bacteria; 2) bacteria and their importance to soil and plant health, intra and interspecific relationships (mutualism, symbiosis).

**Additional information**

Throughout the comic, many words are highlighted and included in a glossary to facilitate understanding of difficult terminology by a non-expert audience. At the end, the book also provides detailed information about some currently hot topics, such as the correct use of antibiotics and the impact of human activity in eutrophication, among others. We also created a card game, freely available for download at http://www.comicbacterias.com/micromatch/, to make microbiology learning even more fun.

**CONCLUSIONS**

We developed a new resource for education in microbiology that helps to engage children in learning and in acquiring accurate knowledge about the amazing microbial
world that is all around us. It is also an excellent tool to help educators teach a complex subject and explain an invisible world. It is expected that teachers will be motivated to use the comic as one tool in their students' learning processes. The effectiveness of the comic in knowledge acquisition has not been assessed in the classroom, so it is necessary to develop systematic evaluation methods. Feedback is welcome at comicbacterias@gmail.com.

SUPPLEMENTAL MATERIALS

Appendix 1: English version of the comic script
ACKNOWLEDGMENTS

This comic was funded by the National Agency for Investigation and Innovation (ANII), PCTI_X_2016_1_131608. The authors have no conflicts of interest to declare.

REFERENCES

1. Eshach H, Fried MN. 2005. Should science be taught in early childhood? J Sci Educ Technol 14:315–336.
2. Kallery M, Psillos D. 2001. Pre-school teachers’ content knowledge in science: their understanding of elementary science concepts and of issues raised by children’s questions. Int J Early Years Educ 9:165–179.
3. Gallego M, Gallego C, Gonzalez C, Atencia I. 2012. Pequeños científicos en el aula de infantil. In: VII Seminario Ibérico/III Seminario Iberoamericano CTS en la enseñanza de las Ciencias, Madrid.
4. Feu M. 2009. Experimentar con materiales. Rev Aula Infant 52:7–10.
5. Gómez-Motilla C, Ruiz-Gallardo JR. 2016. El rincón de la ciencia y la actitud hacia las ciencias en educación infantil. Rev Eureka Enseñanza Divulg Ciencias 13:643–666.
6. McNealy TL. 2013. Connecting music, art, and science for increased creativity and topic engagement. J Microbiol Biol Educ 14:267–268.
7. Heineman RH. 2017. Engaging college students by singing the song. J Microbiol Biol Educ 18(1):18.1.17.
8. Lecky DM, McNulty CAM, Touboul P, Herotova TK, Benes J, Della Monica P, Verlander NQ, Kostkova P, Weinberg J, Goossens H, Adriaenssens N, De Corte S, Holt J, Noer M, Kostkova P, Farrell D, Kremastinou J, Merakou K, Gennimata D, Cornaglia G, Koncan R, Grzesiowski P, Olczak-M, Kostkova P, Farrell D, Kremastinou J, Dellamonica P, Avo AB, Campos J. 2010. Evaluation of e-Bug, an educational pack, teaching about prudent antibiotic use and hygiene, in the Czech Republic, France and England. J Antimicrob Chemother 65:2674–2684.
9. Lecky DM, Hawking MKD, Verlander NQ, McNulty CAM. 2014. Using interactive family science shows to improve public knowledge on antibiotic resistance: does it work? PLOS One 9:e104556.
10. Shurkin J. 2015. Science and culture: cartoons to better communicate science. Proc Natl Acad Sci USA 112:11741–11742.
11. Seitz HM. 2012. Microbiologists just want to have fun. J Microbiol Biol Educ 13:198–199.
12. Bolton-Gary C. 2012. Connecting through comics: expanding opportunities for teaching and learning. US China Educ Rev 4:389–395.
13. Koutniková M. 2017. The application of comics in science education. Acta Educ Gen 7:88–98.
14. Jacobs D. 2007. More than words: comics as a means of teaching multiple literacies. English J 96:19.
15. Hosler J, Boomer KB. 2011. Are comic books an effective way to engage nonmajors in learning and appreciating science? CBE Life Sci Educ 10:309–317.
16. Rozkosz EA, Wiorogórśka Z. 2016. Bibliostory—educational comic stories. A social constructivist approach to media and information literacy education for children and adolescents, p 718–728. In Information literacy: key to an inclusive society. 4th European Conference on Information Literacy, Prague.
17. Farinella M. 2018. Science comics’ super powers. Am Sci 106:218.
18. Farinella M. 2018. The potential of comics in science communication. J Sci Commun 17:Y01.
19. Naylor S, Keogh B. 2013. Concept cartoons: what have we learnt? J Turkish Sci Educ 10(1):3–11.
20. Stephenson P, Warwick P. 2002. Using concept cartoons to support progression in students’ understanding of light. Phys Educ 37:135–141.
21. Tébar MG, Ruiz-Gallardo JR. 2015. Influencia de Concept Cartoons en la motivación y resultados académicos de los estudiantes. Rev Eureka Ensen Divulg Ciencias 12:419–440.
22. Van Den Berg E, Kruit P. 2017. Investigating with concept cartoons: practical suggestions for using concept cartoons to start student investigations in elementary school and beyond. Sci Educ 8:129–138.
23. Tatalovic M. 2009. Science comics as tools for science education and communication: a brief, exploratory study. J Sci Com 8(4): doi.org/10.22323/2.08040202.
24. Massarani L, Rocha M, Pedersoli C, Almeida C, Amorim L, Cambre M, Nepote AC, Aguirre C, Rocha JN, Gonçalves JC, Acerb L, Flávia C, Ferreira B. 2017. Aproximaciones a la investigación en divulgación de la ciencia en América Latina a partir de sus artículos académicos. Available at https://www.redopop.org/lainvestigacion-en-divulgacion-de-la-ciencia/.
25. Simons GF, Fennig CD (ed). 2018. Ethnologue: languages of the world, 21st edition. SIL Int, Dallas, TX.
26. Byrne J. 2011. Models of micro-organisms: children’s knowledge and understanding of micro-organisms from 7 to 14 years old. Int J Sci Educ 33:1927–1961.
27. Ruiz-Gallardo JR, Paños E. 2018. Primary school students’ conceptions about microorganisms. Influence of theoretical and practical methodologies on learning. Res Sci Technol Educ 36:165–184.
28. Karadon HD, Şahin N. 2010. Primary school students’ basic knowledge, opinions and risk perceptions about microorganisms. Proc Soc Behav Sci 2:4398–4401.
29. Dr. Biology. 2014. ASU – Ask A Biologist. Microbes.
30. Peruzzo N, Rodriguez Juelle A. 2018. Bacterias: la historia más pequeña jamás contada, 1st ed. Bandas Educativas-Instituto de Investigaciones Biológicas Clemente Estable, Montevideo, Uruguay.