Statistical tools to assess environmental risks

Laura Martignon[1] and Jaime Martinez[2]
Ludwigsburg University, Germany[1]; Instituto Virgen de Las Nieves, Spain[2]
martignon@ph-ludwigsburg.de

Young people are increasingly aware of the climate crisis, witnessing its effects and actively engaging in discussions and actions towards sustainable behavior. The purpose of the project EduS4EL has been to foster basic competencies of youngsters for critically assessing environmental risks based on reliable data. Specific analytical skills to be developed include risk assessment, data analysis, logical reasoning, and a foundational understanding of environmental issues. This paper explores a set of technological tools designed to help high school students develop these skills through targeted educational interventions focused on experience-based learning.

INTERVENTIONS ON ENVIRONMENTAL LITERACY

Within the framework of the Erasmus + EduS4EL (Educational Strategies for Environmental Literacy) project, empirical studies were carried out at 8 different schools: 2 in Germany, 2 in Italy and 4 in Spain. At some of these institutions-unfortunately not all of them-we had the possibility to implement interventions, with pre- and post-treatment questionnaires, and control groups. The interventions were conceived to familiarize students with serious environmental phenomena caused by climate change, through the systematic use of digital tools. These instruments, created by our team and available on the CODAP platform (Common online data analysis platform, https://codap.concord.org/) provide, on the one hand, data obtained by internationally accepted scientific institutions and, on the other hand, very intuitive tools both for statistical analysis and for gamification with scientific scopes.

METHODOLOGY

This research work was carried out with students of age 15 to 17. We report here on those intervention studies, where pre- and post-intervention tests were implemented with treatment and control groups. Let us first list the activities that constituted the experience-based approach:

Analysis of data

Here, students have to read and work with worksheets that illustrate relevant phenomena caused by climate change. A set of 5 worksheets for this intervention study had been produced by Joachim Engel and his student Kleinknecht on the topics:

- Melting glaciers
- Seal level rising
- August temperatures in Germany
- August temperatures in Granada
- CO2 Vostok

These worksheets list facts about the phenomena described and contain links to CODAP sites with data (previously prepared by the authors) with which students can work and learn.

As a first example, we briefly describe the worksheet on August temperatures in Granada. This worksheet reveals to students that some years, since 1931, have had extreme heat values. The list of these "particular" years is:

- 2003 for having reached the hottest summer ever recorded until then, with a national average temperature of 76.89 °F (24.94 °C), and for having the longest heat wave of the era.
- 2012 for having the longest heat wave until then. On August 10, it affected 40 of the 50 provinces.
- 2015 for having the longest heat wave until then, which lasted 26 daysten days longer than the previous record holder.
- 2017 for being the year with the most heat waves, having had 5, with a total of 25 days. 1991 and 2016 had 4 heat waves each.
- 2023 Spain recorded its highest temperature ever until 2023 in April on Thursday, April 27, 2023 at the Córdoba airport.

In: Birk, L., Loth, G., Jotzo, L., Binder, K., & Frischemeier, D. (Eds.) (2026). *Statistics and Data Science Education in STEAM. Proceedings of the Satellite Conference of the International Association for Statistical Education (IASE), September/October 2025, Münster, Germany*.

The fundamental element of the worksheet is the link to a special site in CODAP, where students can experiment with data and which we describe in the following paragraph.

Students working with CODAP on August temperatures in Granada

To illustrate how students learn about temperatures in August in Granada, we show the graph they open, when clicking on the corresponding link in the worksheet: *https://codap.concord.org/app/static/dg/es/cert/#shared=https%3A%2F%2Fcfm-shared.concord.org%2FpyokeI9J5BOYgpXDNjzy%2Ffile.json*

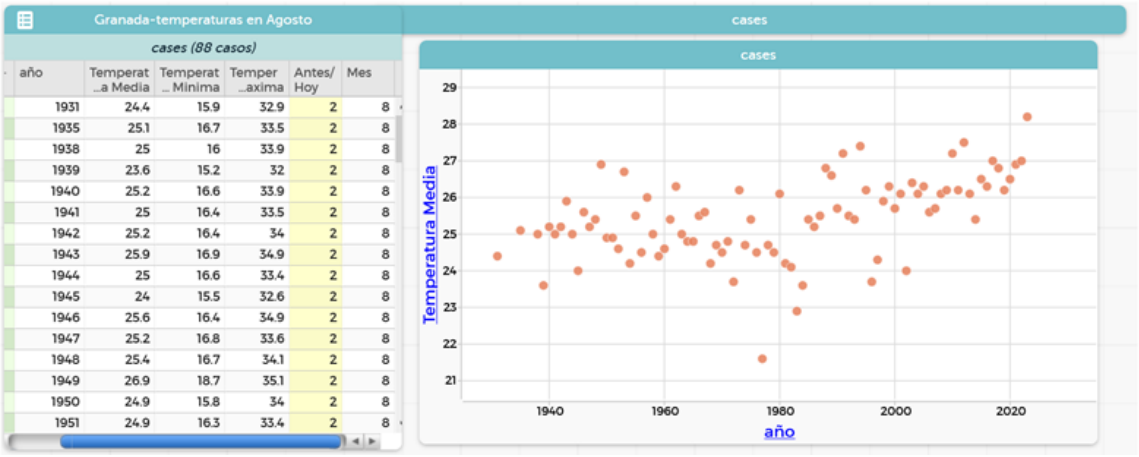

Figure 1. On the left side, we see the table of temperature data from the year 1931 to 1951 and the corresponding graph of the average temperature. The user can extend the table to the year 2023. At the top left of the graph in Fig. 1 is a table with data on the variables: index, year, mean temperature, minimum temperature and maximum temperature for Granada in August.

The many add-ons provided by CODAP can be used by students, with minimal explanation by the instructor.

For instance, students can open up a menu at the right side of the graph, which exhibits tools for statistical analysis:

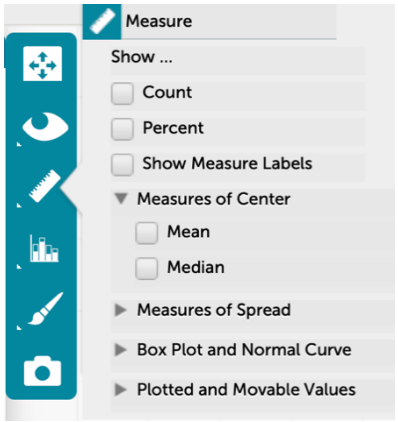

Figure 2. The figure shows the pull-down menu that opens by clicking on the ruler, which consists of statistical tools, such as average, median, boxplot, etc. The language here is Spanish, but the tool is available in English as well, of course.

In addition, students can, for instance, change the color of the data points and draw a trend line, as illustrated below:

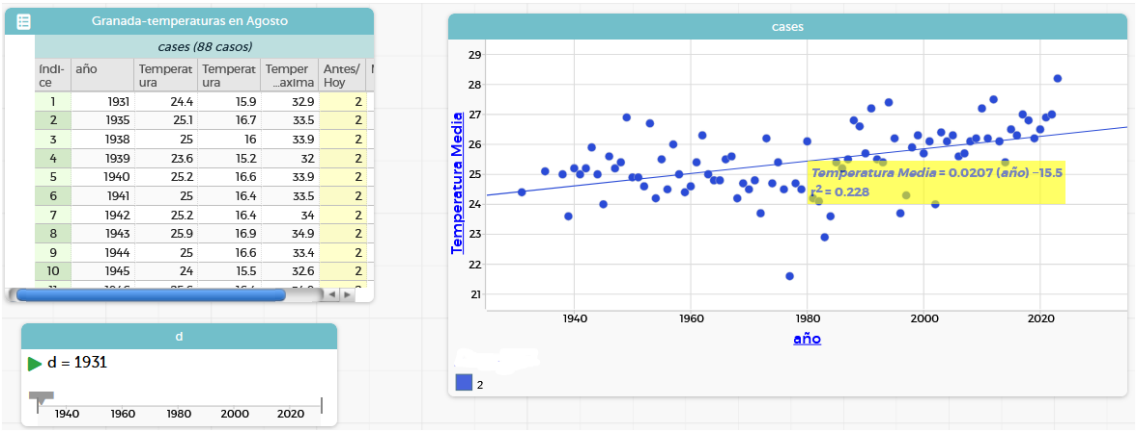

Figure 3. Data points are now blue, and the least squares line is drawn through the data points. The yellow box shows the slope of the line corresponding to the average temperature between the years 1931 and 2023.

Students work with data on "Sea levels rising"

Here students work with a worksheet on sea level variations. In order to work online with CODAP on the topic, they learn about the relevant variables:

Variable name	Possible characteristics	Explanation
Date	From 1880-01-16 until 2009-12-17	Date of the measurement
gmsl (global mean sea level)	Values between -184 and 85	Sea level height, **global mean sea level** Data are given as changes from 1 January 1993 and are 2-month averages measured in mm.
method	Coastal tide gauge records or satellite observation	Records of coastal tide gauges[5] or Satellite measurements[6]

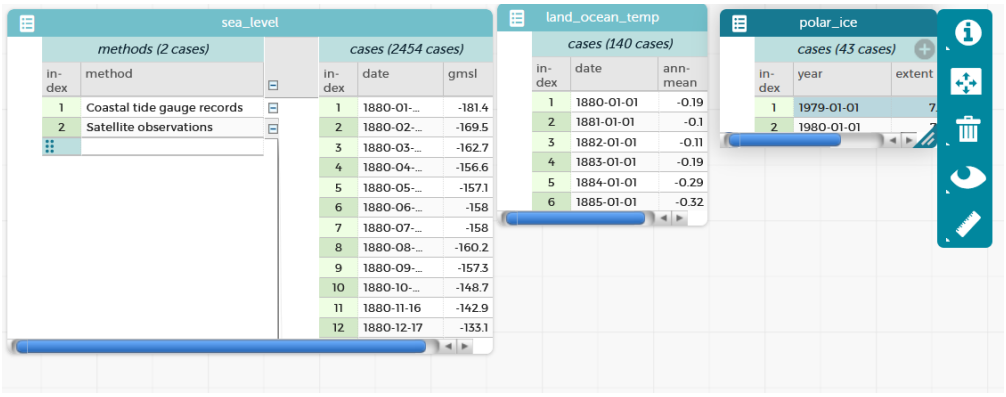

Figure 4. Variables for a statistical and graphical treatment of sea level variation (above) and the case of temperatures in Granada during the month of August (below)

Games for introducing the concepts of risk and of the "Tragedy of Commons"

Gamification has been introduced as an experience-based tool for learning during the last two decades in schools the world over. We now describe games which foster important intuitions for tackling environmental problems. Inspired by the fundamental work by Kahneman and Tverky (1979) on people's choices under risk, Martignon and Hoffrage (2019) tested a task with students aged 9 to 16, which can be briefly described as follows: Choose between a weekly plan of €5/week and another in which every Monday a coin is flipped and if it comes up heads we get €20/week and if it comes up tails

€0/week. The authors observed that 9-year-old girls tend to prefer the safe plan (90%) while boys prefer to risk more (60%).

Lotti

The Lotti game, created by the second author and used in the intervention of the codap.xyz platform in the EduS4EL section, was inspired by this experiment.

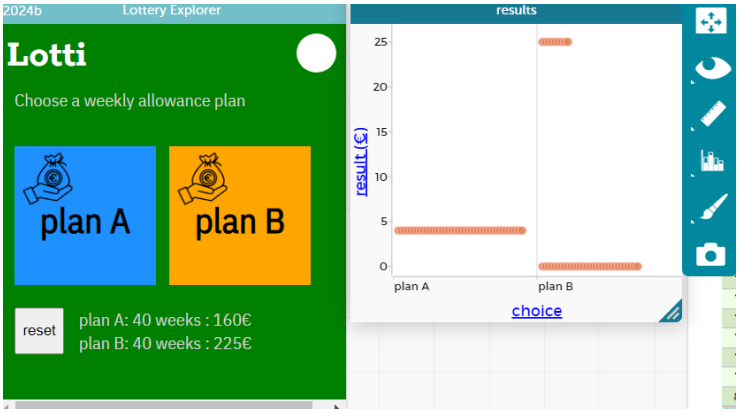

Figure 5. The first panel on the left side presents two ”doors“ to different weekly allowances. The second panel presents the same doors but also the computations of accumulated gains with door A and door B, as well as a graph of the gains.

This simple game, used during all interventions, provided first experiences in assessing risks and the tradeoff between risks and benefits. CODAP offers graphic tools that allow to keep track of the player's gains and losses in the long run. This is an invaluable enrichment, which fosters the frequentistic approach to concepts like probability and expected value. After the experience-based confrontation with Lotti, the instructor conceptualizes risk in simple language. The approach is to present risk as an expected hazard characterized by a probability and an amount of resource X, which can be "lost" with that probability. The intention is for students to later use that concept of risk for their discourse on relevant topics connected to climate change, like forms of energy, etc. Our interventions evaluated the impact of simple games like Lotti on the transfer from risk assessment to serious discussions on climate change problems.

Mazu and the tragedy of commons

Overfishing, overgrazing and deforesting are modern problems that attack our planet. Individual greed and the maximizing utility principle lead to tragedies whenever nature, our basic resource, is considered as basically endless. The example of herders sharing a common parcel of land, which lead to overgrazing was cited by William Forster Lloyd back in 1833 (Lloyd, 1933). More than a century later, Garrett Hardin conceptualized the phenomenon in a famous paper on the ”Tragedy of Commons” (Hardin, 1968). Inspired by Hardin’s work, the second author of this paper produced two plugins as games for experiencing this “Tragedy”: Mazu and Forester. The first is devoted to fishing, while the second is devoted to foresting. In 4 of the school interventions we had students play Mazu. Here there are a number of players who are fishermen and whose purpose is to fish and sell the catch to make a profit to earn a living. Another player has the role of Queen of the Seas, who controls the participation of all the fishermen, allowing the sale in each round of the catch, and deciding how long the game lasts. It ends when the fishing resources are so few that the annual regeneration of the catch is not guaranteed. Although some have had more financial benefits than others, fishermen do not recover as quickly, and the process stops after a few years, which is why said the ultimate result is that everyone ends up losing.

Evaluation of the interventions

Publications which are presently being written and submitted to scientific journals will exhibit extensive results on some of the interventions (see, for instance, Martinez & Martignon, 2025). Here, we briefly mention the ones carried out at the Instituto Virgen de las Nieves. Prior to the interventions,

an initial questionnaire prepared by EduS4EL Project coordinators Laura Macchi and Laura Caravona was presented, which was carried out a second time after the intervention. This questionnaire contained various questions on topics related to climate change, critical thinking (as conceived by Halpern, 1998) and behaviors aimed at caring for the environment.
Here we limit ourselves to showing two results, both reflective of changes of attitude towards solutions to environmental catastrophes.

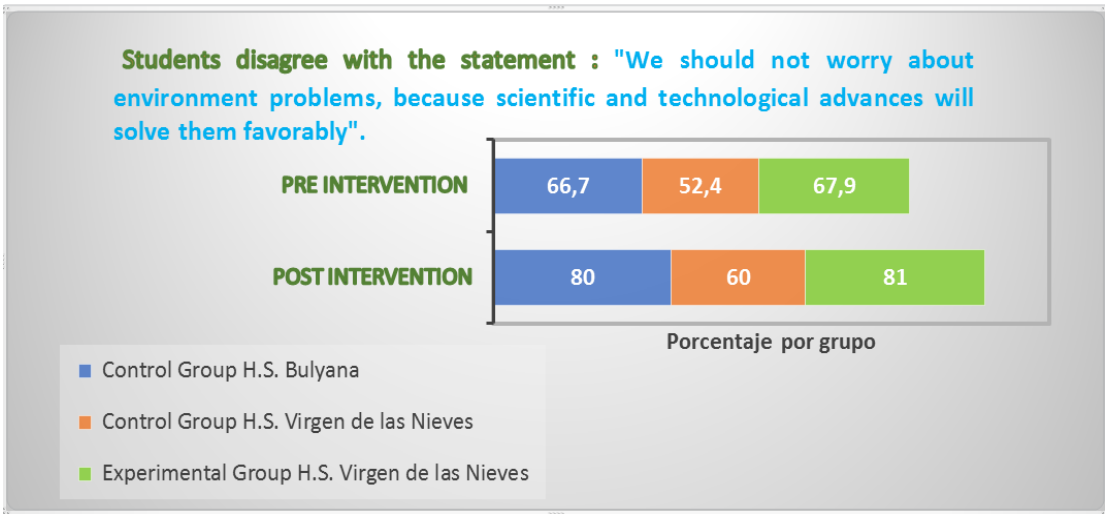

Figure 6. The question here is whether students disagree with the statement: "We should not worry about environmental problems because scientific and technological progress will successfully solve them".

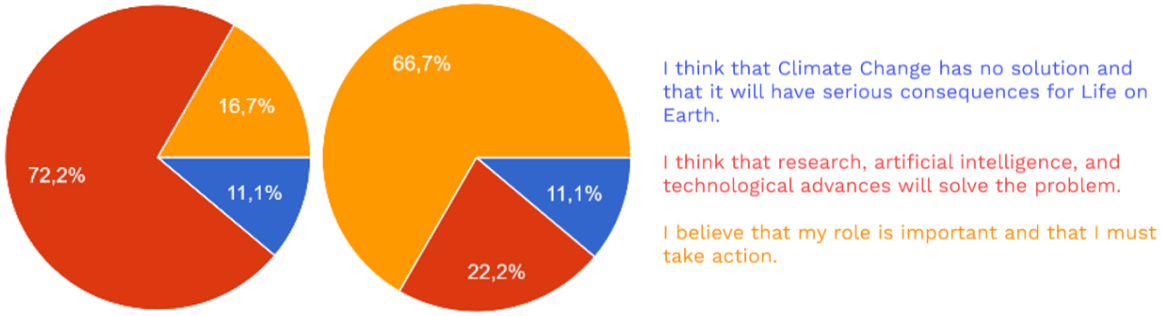

Figure 7. Changes in students' attitudes towards actions to be taken for solving environmental problems.

REFERENCES

Erickson, T., Martignon, L., & Engel, J. (2025 this volume). Economics versus the environment. *promoting systems thinking, sustainability, and collaboration in a "commons" game.*

Halpern, D. F. (1998). Teaching critical thinking for transfer across domains: disposition, skills, structure training, and metacognitive monitoring. *American Psychologist, 53*(4), 449–455. https://doi.org/10.1037/0003-066x.53.4.449

Hardin, G. (1968). The Tragedy of the Commons. *Science, 162*(3859), 13.

Kahneman, D., & Tversky, A. (1979). *Prospect Theory: An Analysis of Decision under Risk. Econometrica*, *47*, 263–292.

Lloyd, W. F. (1833). *Two Lectures on the Checks to Population*. https://archive.org/details/twolecturesonch00lloygoog

Martignon, L., & Hoffrage, U. (2019). *Wer wagt, gewinnt? Wie Sie die Risikokompetenz von Kindern und Jugendlichen fördern können*. Hogrefe

Martinez, J., & Martignon, L. (2025) *Fomentando el pensamiento críticonsobre riesgos medioambientales con actividades digitales*. Submitted to Ensenanza de las Ciencias