

Article

Does Pollution Only Affect Human Health? A Scenario for Argumentation in the Framework of One Health Education

Tamara Esquivel-Martín , José Manuel Pérez-Martín  and Beatriz Bravo-Torija 

Specific Didactics Department, Universidad Autónoma de Madrid, 28049 Madrid, Spain; josemanuel.perez@uam.es (J.M.P.-M.); beatriz.bravo@uam.es (B.B.-T.)

* Correspondence: tamara.esquivel@uam.es

Abstract: Schooling should equip citizens with the scientific knowledge necessary to make informed decisions about health problems arising from the current environmental crisis. Given the scarcity of educational proposals that integrate evidence-based argumentation, One Health education and complexity-based solution proposals, this study aims to introduce a scenario linking the use of pesticides in agriculture to infertility, and to analyse the extent to which it promotes students to apply these three approaches. The activity requires 10th graders to rank 6 cities from most to least polluted, using evidence on the reproductive problems of different organisms in the ecosystem (humans, harlequin flies). Moreover, students have to propose solutions to avoid the toxic risk caused by pesticides. Group discussions are analysed to determine learners' performance in using evidence and formulating causal explanations to justify their rankings, as well as in proposing reasoned solutions, considering different perspectives. The results show that most groups rank cities as expected. Although they do not use all available evidence, the design of the activity encourages students to establish frequent causal relationships between human, animal, and environmental health data (argumentation integrating the One Health approach). Moreover, most solutions are palliative rather than preventive, respond to an anthropocentric interest, and their consequences are rarely assessed. In doing so, students only foresee their environmental or economic impact, but not their ethical or political consequences. Educational implications are discussed.

Keywords: biology education; discourse; environmental citizenship; secondary education; socio-scientific issue; use of evidence



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1. Introduction

The planet is facing an unprecedented environmental and health crisis, but this is not surprising because nature has been warning us for more than fifty years [1]. Although being eco-friendly is fashionable and environmental issues seem to be of concern to society, most people display an attitude of false environmental goodwill, as they continue to engage in unsustainable behaviours [2,3]. It seems that people are only willing to act when their well-being is directly affected [4,5], as has been the case with the COVID-19 pandemic. It has shown that scientists often face problems with no obvious, unique, or immediate solution [6], and that social responsibility plays an essential role in solving health-related issues [7]. The most recent strategy developed to tackle environmental degradation is the 2030 Agenda, which includes 17 Sustainable Development Goals (SDG) [8]. Given the complexity of environmental problems [9], the SDG approach establishes that it is essential to address them holistically (considering the health, sociological, economic, cultural and other perspectives), bringing conceptual, procedural, and epistemic knowledge into play [10].

Since education is the driver of any individual and, therefore, societal change [6], schools must provide students with literacy and awareness-raising opportunities as a prelude to action [11]. This is why current science curricula include topics such as deforestation or pollution [12,13], and advocate engaging learners in active and argument-rich learning environments rather than simply reproducing content.

Therefore, educational interventions should confront students with contemporary environmental socio-scientific issues (SSIs) in order for them to reason scientifically and/or make informed decisions [14], and to encourage them to take preventive actions by and for all [15]. In this sense, scenarios about climate change predominate in the literature [16–18], providing students with short narratives (little variety and quantity of data) explaining the situation. Their main objective is to improve students' knowledge on the issue so that they can construct informed opinions and position themselves in controversies. Sometimes students are also asked to come up with ideas for managing or resolving situations. Regarding the arguments, each study explores different aspects. For instance, ref. [16] analyses the perspective(s) from which the argument is made (e.g., economic, ecological), and [17] further analyses the structural quality of the arguments according to the elements of Toulmin's diagram considered (e.g., warrant, backing, rebuttal). Finally, Ref. [18] adds two categories (emotion and action) to the previous method of analysis. According to these authors, in addition to improving their scientific skills (argumentation and decision-making), students end up with a greater mastery of content (climate science), a better understanding of the nature of science and, in general, a greater awareness of the problem.

Previous examples regarding climate change show that environmental education has tended to prioritise conceptual knowledge and awareness-raising rather than emphasising critical thinking for transformative learning, which is an approach more consistent with the challenges of the 21st century [19,20]. Nevertheless, some recent scenarios have advocated for place-based instruction to change students' attitudes and behaviours, an educational approach that connects the learning process to the physical place (outside the classroom) in which it takes place. For example, Ref. [21] reports that travelling to Yellowstone National Park to understand the impact of wolf reintroduction on the ecosystem through direct observation and expert explanations improved students' knowledge of trophic cascades and food webs, raised their awareness of the need to care for the environment and organisms affected by human intervention in nature, and even increased their willingness to take action to address environmental SSIs.

However, as in the studies mentioned above, the problem of the wolf's disappearance from the ecosystem is not addressed from a health perspective, e.g., linking this super-predator with its role as a "forest sanitary" capable of preventing zoonoses by feeding on sick or dead animals. Therefore, the paucity of studies addressing the relationship between environmental degradation and health is striking (e.g., [22,23]), let alone studies addressing the interrelationship between environmental, animal, and human health [24]. The latter approach, called "One Health", is more common in medical and ecotoxicology publications dealing with issues such as microbial resistance, biodiversity loss, or zoonotic diseases [25,26].

Given the limitations of existing educational intervention proposals, there is a need to broaden the range of activities designed to help students understand the impact of human interventions in the environment (e.g., pollution) on the health of different organisms in the ecosystem. It is also important for students to consider the extent to which different scales of biological organisation (cell, organism, species) are affected [27]. Thus, moving from the microscopic to the macroscopic scale, learners should recognise that poor environmental health affects the health of organisms by altering their cells (cellular level). Going further, students should be aware that harmful pollutants affect the physiology, immune and endocrine responses of individuals (organism level) and can cause serious problems (e.g., reproductive problems). If this occurs in many organisms in the population, the survival of the species may be compromised, and biodiversity may be lost (species level). In addition, if certain organisms disappear from the ecosystem (e.g., top predators such as wolves), the transmission of pathogens between species is encouraged [7]. However, there are a lack of studies that require handling the microscopic scale when interpreting evidence to understand environmental SSIs. Some studies do consider the microscopic scale, but only when addressing possible solutions to reduce environmental stress such as using microorganisms to degrade excess paper, a major contributor to global waste [28].

In summary, the proposals found in the literature for working on socio-scientific argumentation do not tend to focus on the health problems arising from the environmental crisis. When they do (e.g., [29]), they do not usually require linking all the vertices of the “One Health triangle”, but merely analyse how environmental health affects human health or animal health separately. When this interrelationship is considered (e.g., [23], although the term One Health is not explicitly stated), the tasks do not require students to handle the microscopic scale (explanation of health problems at the cellular level). Moreover, studies do not always ask students to propose solutions, and, when they do (e.g., [18]), they often do not analyse whether the impact of implementing them is evaluated. Finally, most scenarios are designed for upper-secondary students (e.g., [16,23]), university students (e.g., [28]), or trainee teachers (e.g., [18]). As a result, the ability of middle school students to identify environmental problems, analyse them, understand their scope, and plan actions to solve them (including those they would be willing to take) by assessing their consequences, remain low [30].

For all these reasons, this study introduces a thought-provoking scenario on a real environmental problem: pesticide exposure and its effects on reproduction, especially on cell division [31,32]. Based on the evidence, 10th grade students must rank the populations of 6 cities according to the degree of exposure to pesticides and the resulting consequences (at the macroscopic/organism and microscopic/cellular levels). Moreover, they must propose solutions to avoid toxic risk, considering possible actions at any level (individual, societal, governmental). Ideally, they should also assess the impact of proposed actions from different perspectives (e.g., ethical, economic), given the relevance of considering SSIs holistically [9]. Addressing this scenario should enable students to answer the title question: “Does pollution affect only human health?” by linking poor environmental health to risks to human reproductive health and to the health of other species (One Health).

Therefore, to cope with this scenario, students need to combine three approaches that are not usually addressed in an integrated way in the literature: “evidence-based argumentation”, “One Health Education” and “complexity-based solutions proposal”. To do so, they should apply scientific skills such as identifying and selecting relevant data, using evidence to construct and evaluate cause-effect relationships, assessing the strength of reasoning and the sufficiency of evidence, or using evidence to support conclusions [12,33]. They should also apply environmental skills such as understanding human actions that degrade the environment and their consequences (literacy and awareness) and, on this knowledge base, propose reasoned solutions to reduce pollution (Figure 1). This goes beyond theoretical knowledge and would bring them closer to action [2].

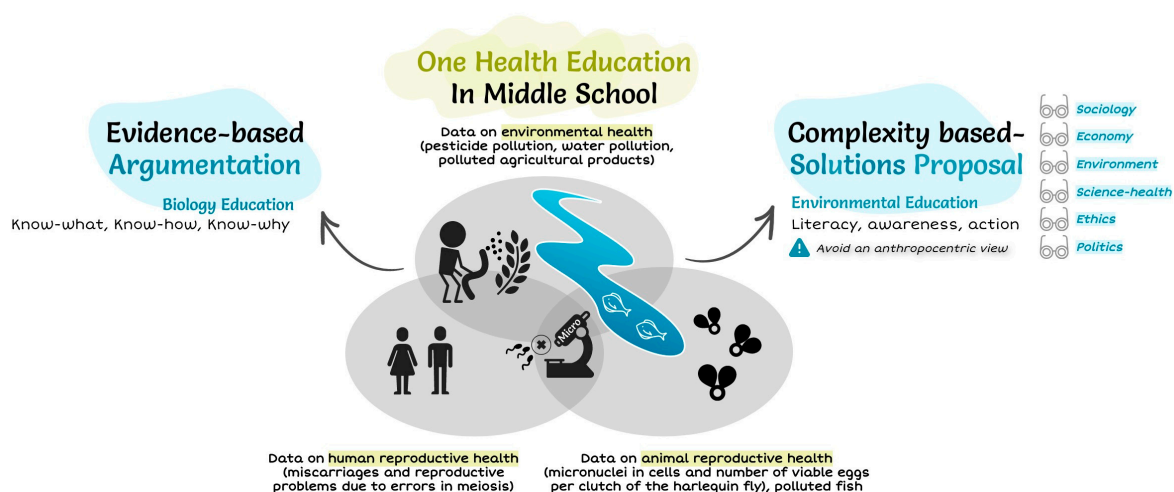


Figure 1. Learning approaches included in the activity. Data on the health of the environment, animals, and people are mentioned, which students should consider when arguing and proposing solutions.

The aim of the research is to check whether the design of the activity allows for the characterisation of students' performance in the scientific practice of argumentation, analysing how they use the available evidence (data on environmental, animal, and human health), as well as the reasoning followed when proposing solutions to avoid the problem. To this end, two research questions (RQ) are addressed as follows:

1. How do students use evidence and formulate causal explanations when ranking cities according to the degree of exposure to pesticides?
2. What solutions do students propose to avoid toxic risk?

2. Method

This study is framed within the case study research method, which consists of exploring a phenomenon (the case) in its real context [34]. Specifically, students' group discussions are analysed to determine their performance in arguing to solve the tasks. These discussions, in the educational context in which they occur, constitute a particular case. Therefore, each group discussion is considered as a different case study, which should be analysed in depth to understand its complexity (multiple case studies). This allows for a better understanding of the meaning of learners' actions throughout the activity and more valuable information as opposed to when a single case is examined [34].

2.1. Participants

The study has been conducted in 2 10th grade biology classrooms belonging to the bilingual section of a Spanish public high school (biology is taught in English). The intervention has been carried out with the permission of the school's management team. As a condition, the anonymity of all participants is guaranteed by using pseudonyms, and the analysis focuses only on academic issues, never on personal or moral evaluations of the participants. The participants are 38 students aged 15–16 (22 females and 16 males) divided into 10 heterogeneous working groups (3–4 members) in terms of students' scientific performance. According to their teachers (both are biology graduates with more than ten years of teaching experience), learners are familiar with the dynamics of guided group work, but not with autonomous and self-directed work to solve open-ended problems. However, their involvement in the task has been high (hardly any downtime). Knowing that the activity would not be graded by teachers has encouraged them to express their ideas freely.

2.2. Activity: "If It Happens to You, It Can Happen to Me"

The designed activity is framed in a didactic sequence focused on improving the teaching-learning of cell division, described in [27]. The first activity in the sequence, detailed in [35], relates cancer treatment to alterations in mitosis. Students are only provided with visual information (micrographs), from which they have to extract evidence to solve the case, based on their previous theoretical and practical training. Therefore, the key skill is the correct interpretation of micrographs, understanding mitosis as a continuous process in which each event is essential for the next to occur.

However, in the present study (third activity of the sequence), which relates pesticide exposure to alterations in meiosis (reproductive problems), learners receive information expressed in different semiotic modalities (visual, numerical, textual) and from different sources (map, news, report) which they must interpret and relate to each other. It should be noted that each semiotic modality provides different but complementary information. Therefore, all data must be interpreted as a whole. In order to draw valid conclusions, the most important skills are to identify the relevant data and establish functional causal relationships between them. During the intervention, concepts that are rarely mentioned in 10th grade science classrooms (e.g., toxicology, micronuclei) are introduced to check if students can connect them to their prior knowledge. The intervention lasts fifty minutes and is divided into two phases (Figure 2).

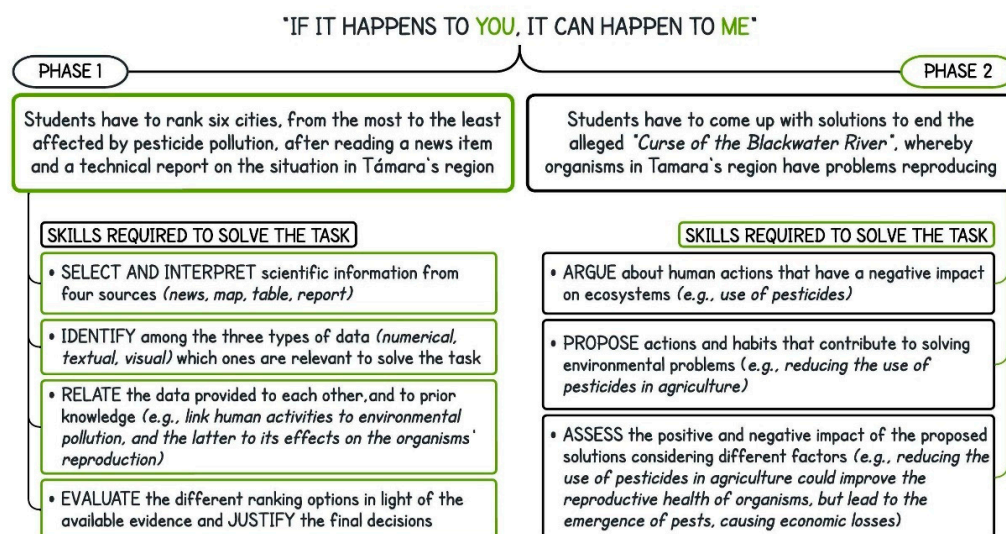


Figure 2. Activity phases, tasks, and skills needed to solve them.

2.2.1. First Phase (Associated with RQ1)

Students start reading a fictitious Facebook news (Supplemental Material, News S1) about the reproductive problems that pesticide pollution has caused for the inhabitants of Támara (Figure 3a). After reading it, teachers ask them to hypothesise what biological process(es) could be altered to explain the reproductive problems in the population. In answering, students should consider the possibility that an abnormality has occurred during meiosis, as this is the process during which the gametes necessary for sexual reproduction are produced. After the groups reflect on it, the teacher focuses the problem of reproduction on meiosis, providing them with a technical report, which contains a data table (Figure 3b) and its complementary text (Supplemental Material, Report S1).

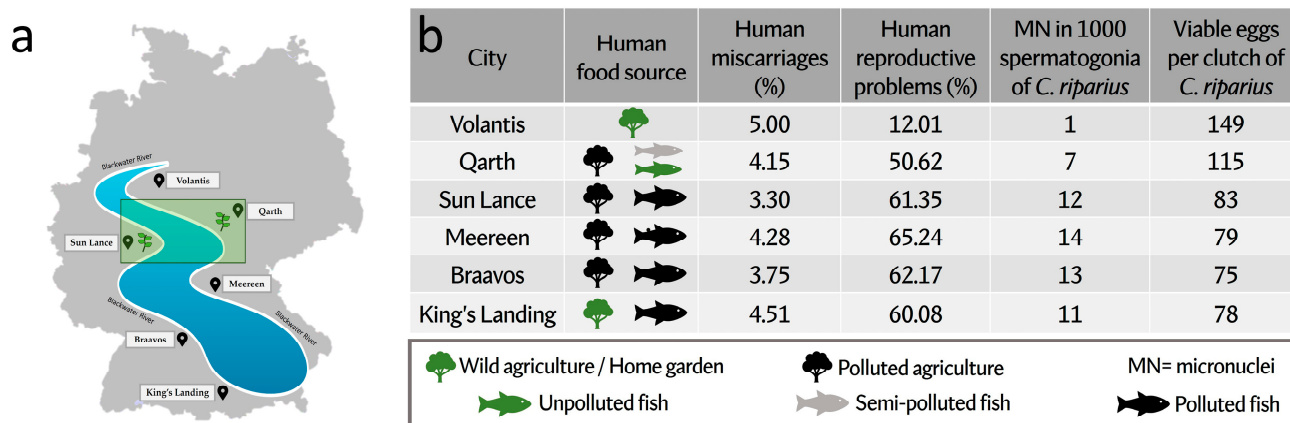


Figure 3. (a) Map of the region of Támara with farmland in a rectangle; (b) table of data on food sources and reproductive health of humans and harlequin flies (*Chironomus riparius*) in the six cities.

Groups are asked to rank the cities according to the degree of exposure to pesticides (higher exposure leads to more reproductive problems), specifying what data support their answers and why. Although there is no single solution, the following ranking of populations, from most to least harmed, could be assumed as a reference response: Meereen > Braavos > Sun Lance > King's Landing > Qarth > Volantis.

To reach this conclusion, students should relate and synthesise as much information as possible (Supplemental Material, Table S1). Thus, they must first associate the pesticide use (general cause) with the development of reproductive problems (general effect). They should then relate the specific causes (e.g., food sources) to the differences observed between

cities in terms of effects at the cellular level (e.g., errors in meiosis) (Figure 3b). Moreover, students must distinguish which data relate to humans (e.g., miscarriages) and which to harlequin flies (e.g., viable eggs per clutch) in order to relate the reproductive health of the two species (Figure 4). Furthermore, to train students to distinguish relevant from irrelevant information, and to emphasise the importance of considering all available data together, a numerical distractor is included in the table: miscarriage rates—but the text of the report specifies that “there are no significant differences between cities”.

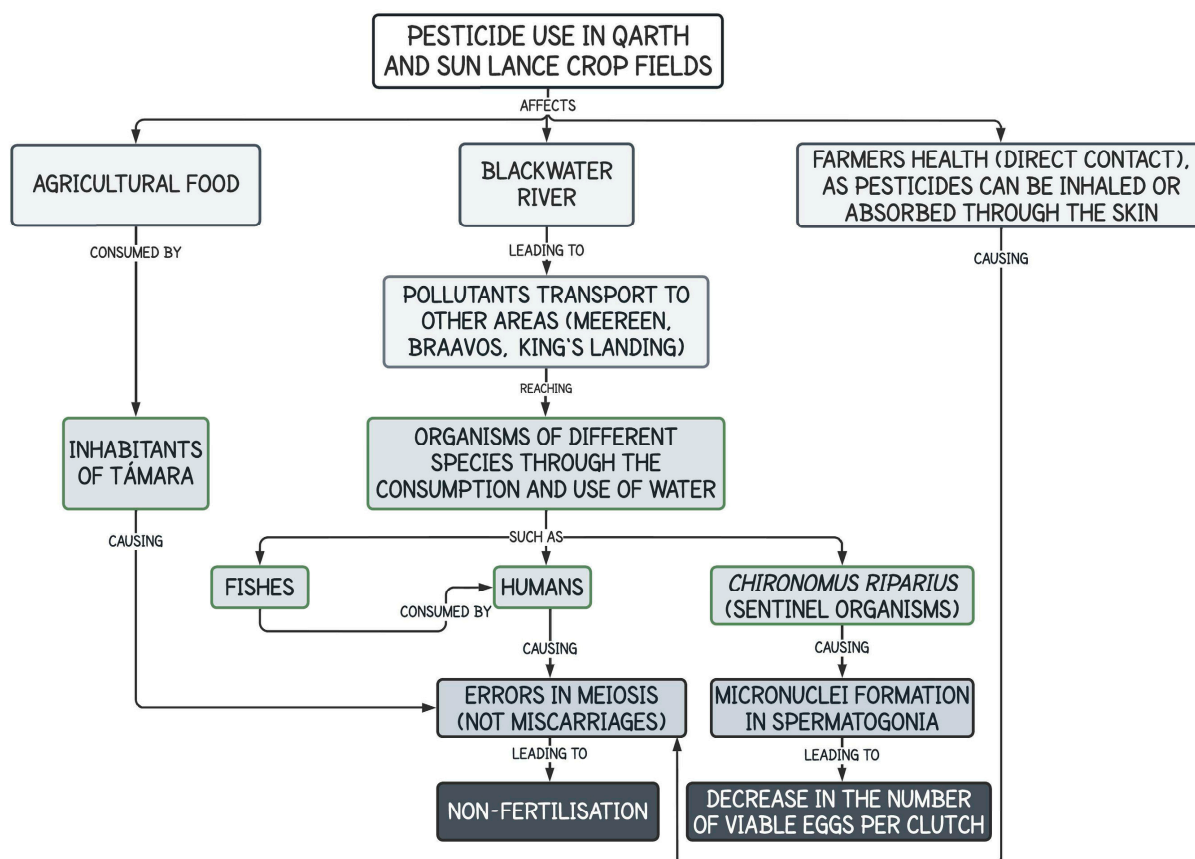


Figure 4. Conceptual map of the reference response.

2.2.2. Second Phase (Associated with RQ2)

Students must suggest solutions to the pollution problem. Additionally, they are expected to assess the impact of the implementation of their proposed actions from different perspectives. For instance, they should consider the culture of Támara, as its inhabitants are used to being self-sufficient in agricultural products and fishing, so the changes should allow them to maintain this tradition (sociological perspective). They could also think about how to decrease the toxic risk caused by the indiscriminate pesticide use (environmental perspective), thereby reducing costs for farmers (economic perspective), and improving the reproductive health of humans and the harlequin fly (health perspective).

2.3. Data Sources and Data Analysis

This work is framed within qualitative content analysis [36]. Data sources are transcripts of ten small group discussions from audio recordings. As for RQ1, to analyse the reasoning followed by students to rank cities, three steps were followed (Table 1):

Table 1. Data analysis process in the first phase of the activity.

Step	Task
1	Identify in transcripts utterances or sequences of utterances (hereafter situations) in which learners recognise relevant data and integrate them into discourse.
2	Assign each situation a code from Figure 5 by using ATLAS.ti 7 software [37]. Concerning this step, previous studies on argumentation [38] emphasise the relevance of assessing students' performance in the following: identifying and interpreting data, recognising patterns in them; relating evidence with each other and with theoretical models; integrating evidence to justify a choice; or evaluating different options based on evidence. Based on these skills, seven categories (codes) have been defined. Each code requires more complex skills than the previous one. After two cycles of analysis, 87.84% intercoder agreement was reached, which is considered acceptable [36]. Disagreements were resolved through discussion.
3	Represent the evolution of codes throughout the group discussions (<i>codelines</i>) [39].

The results of the analysis make it possible to determine the groups' performance according to whether, when justifying their rankings, situations in which they only integrate data (codes I–III) or those in which they formulate causal explanations (codes IV–VII) predominate. In the latter cases, performance is higher if causal or multi-causal relationships considered in the reference response are established (codes V–VII). To demonstrate this, the sum of the situations to which codes VII, VI and V have been assigned is divided by the total number of codes in each group (ratio).

To answer RQ2, four steps were followed (Table 2).

Table 2. Data analysis process in the second phase of the activity.

Step	Task
1	Identify situations in which students propose solutions, pointing out their purpose using open codes in ATLAS.ti (Figure 6).
2	Group open codes into two code families: "Prevent" or "Mitigate/maintain", depending on whether the solutions aim to eradicate the problem or to restore the damage (Figure 6).
3	Identify situations in which learners evaluate the impact of applying their solutions.
4	Assign each situation in step 3 a code that refers to the perspective(s) of the SEE-SEP model [16] that students have considered when assessing the impact of implementing the proposed solution. The SEE-SEP model is composed of six thematic areas (perspectives) that should be considered when arguing about SSI (Table 3). In our study, we use the model to determine the perspective from which students evaluate the consequences of the solutions they propose, but only in cases where, in addition to proposing a solution, they assess its feasibility. We have added the health perspective to the scientific perspective of the study conducted by [16], creating a new category: science-health, as advances in scientific research are aimed at improving public health.

The results of the analysis make it possible to determine the groups' performance at two levels: (a) groups perform better if they propose a greater number of solutions aimed at preventing the situation from recurring than at mitigating/restoring the damage; (b) groups perform better if they evaluate the consequences of carrying out the proposed actions, and if, in doing so, they consider several (two or more) perspectives of the SEE-SEP model.

	CODE	STUDENTS ARE ABLE TO...
Establishing causal relationships	VII	Relate an effect to more than one cause or a cause to more than one effect at the cellular level <i>Denisse (Group C): There is an increase of micronuclei (first effect) with pesticides (cause), that is why the most polluted cities, which are Meereen and Sun Lance, have more micronuclei (harlequin flies have them). And the more micronuclei, the fewer viable eggs per clutch (second effect)</i>
	VI	Relate only one cause to one effect at the cellular level <i>Eve (Group B): During meiosis in harlequin flies to form gametes, the DNA does not separate properly and part of it remains outside, forming micronuclei (definition's interpretation). In other words, all DNA should be in the nucleus, but this is not the case due to an error in meiosis (effect) caused by pesticide pollution (cause)</i>
	V	Relate causes to causes, effects to effects, or causes to effects, which are considered in the reference response, but not at the cellular level <i>Pauline (Group J): Pesticides end up in rivers, and water spreads them everywhere. They also evaporate, so we end up breathing them in because they are in the air, we drink them because they are in the water; and we eat them because this water is used to water vegetables; and animals also drink this water (she is linking different causes, without explaining how they affect humans and animals at the cellular level)</i>
	IV	Establish cause-effect relationships between data provided by the task and/or prior knowledge, which do not match the reference response <i>Mark (Group D): I think in Volantis there are more miscarriages (effect) because the food source is wild agriculture (cause), and not all of it is good or edible (meaning easily digestible) or has all the nutrients that are needed such as protein, so the defences of those people are lower</i>
	III	Distinguish and interpret textual, numerical, and/or visual data together, establishing patterns and relationships among them <i>Ingrid (Group G): There are more miscarriages in Volantis (numerical data in the table), but it seems the best (means the least exposed city) Helen: In Volantis, which seems to be the healthiest, there is no fishing (visual data in the table) and it says here (textual data in the report) that they are vegan</i>
Integrating available data	II	Distinguish between the relevant and irrelevant in numerical and/or visual data, interpreting and identifying patterns (e.g., differences and similarities between columns) <i>Rachel (Group C): Although in Volantis the percentage of miscarriages is higher (numerical data in the table), Meereen has polluted agriculture and fisheries (visual data in the table) Denisse: But of these three (Meereen, Qarth and Sun Lance), think about it, the miscarriages' percentage does not have to be a significant number because this is a 5,00 (Volantis), and here supposedly it is not polluted, and here it has 4.51 (King's Landing) (numerical data in the table)</i>
	I	Distinguish between relevant and irrelevant information only among textual data, without establishing relationships with the remaining data <i>Lucy (Group A) (At the end of the session, checking the final ranking of cities): Okay, here (textual data in the report) it says that the problem is not that there are more miscarriages because the embryo suddenly dies, but that the zygote does not form because the gametes do not "come together"</i>

Figure 5. Categorisation system for the first phase of the activity (RQ1): codes, definitions, and examples (in italics).

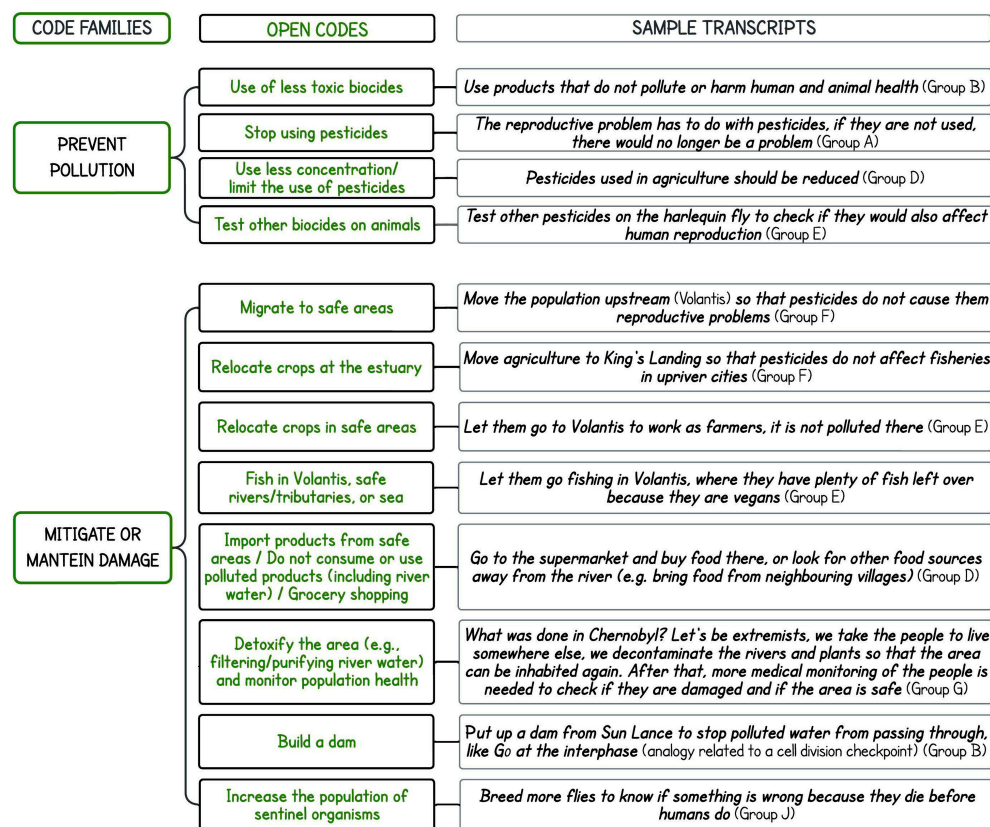


Figure 6. Coding of solutions according to their purpose and examples (in italics).

Table 3. Application of the SEE-SEP model to this study. Codes, definitions, and examples.

SEE-SEP Codes	Definitions	Examples
Sociology	The sociological perspective considers the social and cultural aspects of the problem (social identities, traditions, human relations) which are influenced by the proposed solutions.	Not considered by students.
Economy	The economic perspective considers any monetary aspects (e.g., production costs, economic savings, distribution of resources) related to the proposed solution.	Solution: Limit or cease the use of pesticides. Impact assessment: If pesticides are not used, there would be pests, and that would mean serious economic losses (Group C).
Environment	The environmental perspective considers the effects of proposed solutions on the environment, and on the interactions of organisms with each other and with their environment.	Solution: Relocate crop fields near the estuary. Impact assessment: Pesticides would continue to pollute the sea (Group B).
Science-health	The scientific-health perspective examines possible ways to improve public health based on scientific research in experimental sciences, as well as the possible health consequences of proposed actions.	Solution: Testing different pesticides on flies. Impact assessment: Pesticides that least affect the reproductive health of harlequin flies should be used in agriculture because they would also least affect the reproductive health of humans (Group E).
Ethics	The ethical perspective considers the ethical implications or moral judgements arising from the proposed solutions.	Not considered by students.
Politics	The political perspective considers the relationship between proposed solutions and existing laws or regulations.	Not considered by students.

3. Results and Discussion

3.1. Final Ranking of Cities and Students' Performance in Using the Available Evidence

Regarding the ranking of cities, all groups are hesitant when evaluating their options (feeling uncertain about making a decision), which is common when dealing with SSIs [38]. However, all groups except H conform to the expected ranking in the reference response. Group H wrongly considers Qarth to be more exposed to pesticides than Sun Lance and King's Landing as it is closer to farmland (criterion of proximity).

Considering the groups' performance in integrating evidence into their justifications and formulating causal explanations (Table 4), all groups except D spend most of their discourses relating causes to effects (codes IV–VII), instead of merely interpreting data and/or detecting patterns (codes I–III). In 16/74 situations, they link a cause to a cellular effect (code VI). Even in 4/74 situations, students manage to connect several causes and effects (code VII). The remaining causal explanations are not considered in the reference response (20/74) (code IV), or do not reach the cellular scale (code V, 13/74). Specifically, the groups with the highest performance are A and H (ratio 0.67), whose discourses are dominated by valid monocausal and multicausal relationships between the data. The lowest performance is that of group I (ratio 0.00), which does not formulate any valid causal explanation to solve the task, followed by group D (ratio 0.20), in which justifications integrating isolated data predominate. The remaining groups show an intermediate level of performance.

Table 4. Distribution of the codes in the ten groups. To determine students' performance, the ratio of the subtotal VII+VI+V to the total number of codes in each group is given in brackets.

Groups	Codes										Total
	VII	VI	V	Subtotal VII+VI+V	IV	Subtotal VII+VI+V+IV	III	II	I	Subtotal I+II+III	
A	1	3	2	6 (0.67)	1	7	0	1	1	2	9
B	1	1	1	3 (0.38)	2	5	1	2	0	3	8
C	1	1	2	4 (0.50)	1	5	1	2	0	3	8
D	0	2	0	2 (0.20)	2	4	1	4	1	6	10
E	0	2	1	3 (0.50)	2	5	1	0	0	1	6
F	0	1	2	3 (0.38)	3	6	2	0	0	2	8
G	1	1	3	5 (0.50)	4	9	1	0	0	1	10
H	0	3	1	4 (0.67)	1	5	0	1	0	1	6
I	0	0	0	0 (0.00)	1	1	1	0	0	1	2
J	0	2	1	3 (0.43)	3	6	1	0	0	1	7
Total	4	16	13	33 (0.45)	20	53 (0.72)	9	10	2	21 (0.28)	74

Below, to help understand the discourse analysis of each group that has been carried out to determine their levels of performance, the reasoning followed by group F in ranking the cities is detailed. This serves as an example to understand the reasons why groups move from one level of evidence use to another. In addition, similarities and differences with the other groups are discussed. In group F, students start discussing the Facebook news without considering whether it is reliable or whether its content is sufficient to solve the task (no group shows scepticism). This could be because students do not usually doubt the rigour/adequacy of the information provided by teachers or researchers [40]. Through teamwork, all members eventually establish a link between "pesticide use" (cause) and "meiotic errors" (effect) (U8) (Table 5). It should be noted that, in addition to group F, only Group A discusses the possible effect of pesticides on meiosis, causing reproductive problems. Gaby (Group C), although not specifying meiosis, mentions a possible mutation

from consuming polluted products that prevents species from reproducing. The remaining groups are unable to relate macroscopic consequences to microscopic causes.

Table 5. Excerpt from the discourse of group F classified as code VI.

Turn	Speaker	Utterance (U)
1	Archie	<i>Meiosis must be altered because people cannot reproduce</i>
2	Elisa	<i>Then, as the water is polluted by pesticides, so are the cells</i>
3	Archie	<i>Look! The report states that pesticides have been classified as carcinogenic or endocrine disruptors</i>
4	Elisa	<i>Thus, they affect the endocrine and reproductive system</i>
5	Coraline	<i>What does that mean?</i>
6	Elisa	<i>That means what Archie said is correct (the data read reinforce his idea)</i>
7	Coraline	<i>So, gametes do not undergo meiosis to form gametes</i>
8	Elisa	<i>You are wrong, pesticides prevent meiosis from occurring and gametes from forming</i>

When the teacher distributes the report, group F establishes a new causal relationship between “proximity to the pollution source” (cause) and “miscarriages and reproductive problems” (effects, without reaching the cellular level) (U9–12, Table 6).

Table 6. Excerpt from the discourse of group F classified as code V.

Turn	Speaker	Utterance (U)
9	Elisa	<i>Which city will be the most affected? It will depend on the miscarriages’ percentage and reproductive problems</i>
10	Archie	<i>Look at the map, pesticides are used here, so the most affected cities must be close by</i>
11	Coraline	<i>So, they are Volantis and Qarth</i>
12	Elisa	<i>I disagree, it would be Qarth and Sun Lance (seems to consider that the crop fields are downstream of Volantis)</i>

Then Archie refutes Elisa by pointing out that the people of Volantis must be the most affected by pesticide exposure (effect) because they are vegans (cause) and ‘*only eat polluted food from farmland, while in the other cities people also eat meat*’. This is a relationship not considered in the reference response (code IV). He is ignoring both the table legend (Figure 3b), which specifies that the inhabitants of Volantis feed on unpolluted vegetables, and the text about their home gardens. Difficulties in considering all available data are common in argumentative environments [41], in this case, because students do not check all information sources before attempting to solve the task.

After placing Volantis first, Archie (U13) considers the river direction to rank the remaining cities [the closer to the farmland (cause), the more reproductive problems (effect)] (Table 7). In U15, Archie also introduces the idea of pollutant accumulation, as the river carries pesticides to cities near the estuary. Coraline realises that this idea contradicts the first criterion, highlighting its limitations: if downstream cities are more polluted, Volantis cannot be the first in the ranking. Archie decides to ignore it (U17). This often occurs when students (and even teachers) try to ‘fit’ evidence to their claims, using only the information that supports their hypothesis [10,41,42].

Table 7. Excerpt from the discourse of group F classified as code V.

Turn	Speaker	Utterance (U)
13	Archie	<i>Sun Lance is the second-most exposed city since it is the closest to farmland, then Qarth, and then downwards. Wait, the river forms up here and goes towards the sea, right?</i>
14	Coraline	<i>I think so, rivers originate in mountains</i>
15	Archie	<i>So, cities further downstream should be more affected because the river transports pesticides . . .</i>
16	Coraline	<i>But... you said the most polluted is Volantis, right?</i>
17	Archie	<i>Well, let us leave it at that</i>

Coraline turns to the report for clarification and, after re-reading that the inhabitants of Volantis are vegan (textual data) and checking their location (visual data), she states that Volantis may not be the population most affected by pesticide use, integrating this information into the discourse (U18, Table 8). This highlights the relevance of each learner individually examining the available data to correct their own and their peers' misconceptions or intuitions during the co-construction of arguments. It also shows that the moments of discourse in which data are interpreted and integrated into justifications (codes I-III) are also necessary. In this way, the causal relationships subsequently established between them are more likely to be in line with expectations, thus improving the overall groups' performance.

Table 8. Excerpt from the discourse of group F classified as code III.

Turn	Speaker	Utterance (U)
18	Coraline	<i>I think we are wrong . . . although Volantis' inhabitants should be the most affected because they are vegans, Volantis is not within the pesticide rectangle (Figure 3a)</i>
19	Archie	<i>Right, then they will not eat as much food from farmland</i>

When Ms. Irina asks the students which population suffers the greatest consequences (effect) from pesticide pollution, they answer Volantis due to veganism (cause) (Table 9). She advises them to check the data table in the report (U25), as Archie claims that they have not consulted it. At this point, it is worth noting that teachers hardly intervene during the activity until the final sharing, leaving the working groups free to solve the tasks autonomously. However, scaffolding in this type of situation is essential, using thought-provoking questions to encourage students to reflect and rethink their answers [27].

Table 9. Excerpt from the discourse of group F classified as code IV.

Turn	Speaker	Utterance (U)
20	Coraline	<i>Volantis is the city most affected by pesticides</i>
21	Ms. Irina	<i>Why?</i>
22	Coraline	<i>Because its inhabitants are vegans</i>
23	Ms. Irina	<i>But . . . does the table show that they have more reproductive problems?</i>
24	Archie	<i>We have not seen it!</i>
25	Ms. Irina	<i>You should</i>

At Ms. Irina's suggestion, students look at the table and change Volantis to Meereen, as it has "higher numbers in almost everything" (Table 10). However, after assuming that Volantis is less exposed to pesticides, learners do not understand why it has the highest percentage of miscarriages (U27), and even wonder if it is related to the viable eggs number, as it is also higher (U29-30).

Therefore, students have not realised that miscarriage rates are irrelevant data. No group does, although group C hints at it (example of code II in Figure 5). Failure to discern relevant data from irrelevant data influences the way the problem is interpreted, and the final conclusion drawn [43]. In fact, all groups consider miscarriages to be another effect of pesticide use. When some groups (e.g., D, G) use miscarriage rates as a criterion for ranking cities and try to integrate the other evidence into their justifications, contradictions arise. However, unlike the findings of [41], instead of ignoring the inconsistencies, they overcome the "my-side bias" by addressing the weaknesses of their first position [44] and looking at the available evidence for another possible cause of miscarriages in Volantis: veganism, which "leads to a lack of nutrients and defences" (example of code IV in Figure 5).

Table 10. Excerpt from the discourse of group F classified as code III.

Turn	Speaker	Utterance (U)
26	Coraline	<i>Too bad, guys. Volantis has the highest percentage of miscarriages, the lowest percentage of reproductive problems, the lowest number of spermatogonia (she means micronuclei), and the highest number of viable eggs. I do not know what that means, but they have unpolluted wild agriculture</i>
27	Archie	<i>Why does Volantis have more miscarriages if it is not polluted?</i>
28	Coraline	<i>... and the highest number of “riparius” clutches or whatever. I think the most polluted cities are Meereen, Braavos, and Sun Lance because Qarth has polluted agriculture but unpolluted fisheries. The others have polluted agriculture and fisheries. Meereen first because, of these three, it has the highest percentage of miscarriages and the highest percentage of reproductive problems</i>
29	Archie	<i>But... why does Volantis have the highest percentage of miscarriages? Perhaps the number of viable eggs has something to do with it?</i>
30	Coraline	<i>I agree, because in Volantis there are also more viable eggs per clutch</i>
31	Archie	<i>But what do these insects have to do with miscarriage?</i>
32	Coraline	<i>I have no idea; my brain is going to explode</i>
33	Archie	<i>Report says that only natural pregnancy terminations have been considered (he goes back to the text to try to understand it)</i>
34	Coraline	<i>Anyway, I think that first Meereen, then Braavos ...</i>

In terms of handling and relating new concepts, group F is unable to connect the data on “micronuclei” and “viable eggs”. Although students identify differences and/or patterns among the numbers in the columns (Figure 3b), they show difficulties in interpreting the table meaning due to a lack of theoretical knowledge. Therefore, to address such activities, it is not enough to deal with discrete concepts, but learners need to connect them in a functional way [35,42], which is challenging (U32).

Finally, Archie misunderstands the definition of a sentinel organism and believes that harlequin flies are responsible for the high miscarriage rate in Volantis (code IV): “*The report states that harlequin flies provide early warning of danger to humans. As there are more of these insects dangerous to humans in Volantis because no pesticides are used there (cause), there are more miscarriages (effect)*”. This diminishes the quality of the argument, as aligning data with a proper theoretical framework is essential for sound reasoning [38].

It is striking that despite having doubts about some data, students do not check all the information. Findings show that they prefer visual and synthesised data (map, table) rather than abstract/technical text (code II predominates over code I in Table 4). Moreover, when they need to consult the text to interpret numbers and images (code III), they only read some fragments, skipping relevant information. This could be because students seek to make decisions quickly [23], but considering all available data are essential to truly understand the problem and make a quality decision [12].

However, some students manage to integrate the newly concepts (e.g., micronuclei, sentinel organism) into their justifications and even explain them to their peers. For instance, when George (Group B) interprets: “*micronuclei open holes in the fly eggs cutting the spermatozoa*”, Eve corrects him, sharing her interpretation of the micronuclei definition and relating micronuclei to pesticide pollution (example of code VI in Figure 5). Therefore, she overcomes the epistemological obstacle posed by such abstract concepts [43]. Furthermore, when Martha (Group J) says: “*I do not understand about the flies*”, Pauline uses a self-generated analogy to clarify it: “*Sentinel organisms are like an earpiece that warns humans of danger*”, which is a useful peer facilitation technique during collaborative reasoning [45]. Hence, students should be encouraged not to use evidence thoughtlessly [46] and to interrelate data on human, animal, and environmental health, which is one of the main objectives of the activity, within the framework of developing environmental citizenship [24,47].

The example above also shows how the codes of group F evolve over time. When compared to the evolution of the codes of the other groups (codelines), Figure 7 shows that all groups except B, D, and E establish causal relationships between the data provided from the beginning (codes IV–VI). Later in their discourses, they look for other relevant data

to rank the cities (codes I–III). This allows the learners to evaluate their previous causal explanations (keeping or discarding them) and to formulate new ones (codes IV–VII).

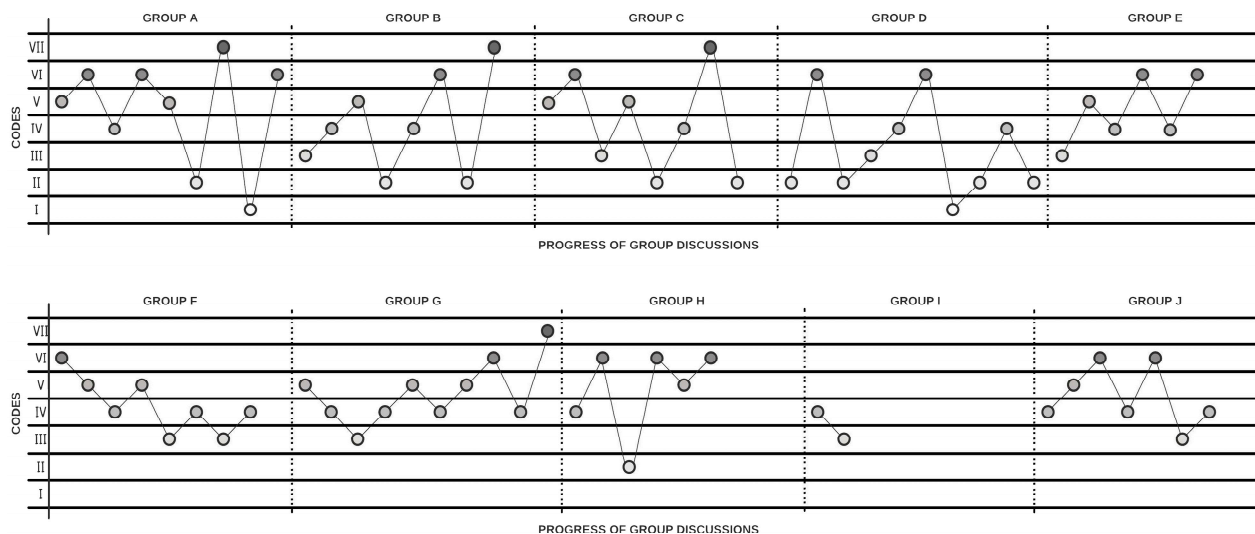


Figure 7. Groups' codelines: evolution of codes over time.

It is worth noting that some of the intermediate codes are higher than the final ones since in a natural conversation it is not necessary to justify many statements if learners assume that they share knowledge [38]; but if one needs to convince or refute a peer, it is when more data are related [44]. Furthermore, although only four groups (A, B, C, G) reach code VII, code VI appears in all groups except I, as it is easier to relate an effect to a cause than to explain multivariate causality, with multiple contributors to the same outcome(s) [46].

Finally, groups G and I are a good example to show that the level of performance is not determined by the conclusion drawn (ranking of cities), but by the underlying reasoning expressed by the students, as both groups rank cities correctly, but their performances are very different. The discourse of group G is dominated by situations in which students relate data (9/10 codes). Five of them match the reference response (codes VI–VII). At the end of the session, they manage to relate several causes (pesticide use, proximity of cities to farmland, transport of pollutants by river) to the formation of micronuclei in harlequin flies (cellular effect) (code VII). In contrast, group I starts by relating pollution (cause) to the occurrence of malformations or the transmission of viruses (HIV) and parasites (Anisakis) (code IV). After reading the report, they rank the cities based solely on food sources and the percentage of reproductive problems in humans (code III), since learners, for the sake of simplicity, tend to use evidence in isolation rather than linking data [44].

3.2. Students' Performance in Proposing Reasoned Solutions

Table 11 shows the solutions proposed by each group. Although they were asked to think about actions to end the toxic risk in Támara, in most situations (28/42), learners focus on decontamination rather than non-recontamination, mainly by proposing unsustainable actions (e.g., importing non-polluted products, decontaminating Támara).

In terms of groups' performance, only group H proposes more preventive than palliative solutions, showing a better performance (ratio > 0.5). In groups D and G only two solutions are proposed, one of each type (ratio = 0.5). The remaining groups (A, B, C, E, F, I, J) are dominated by solutions aimed at mitigation rather than prevention (ratio < 0.5). Therefore, it seems that students find it easier to reflect on how to restore a situation than on how to ensure that it does not happen again, although the SDG approach calls for educating for the future, thinking about long-term solutions [8]. Global society has shown a similar attitude during the COVID-19 pandemic, considering vaccination as the main short-term

solution. However, it does not prevent the emergence of new pandemics. To achieve this, it would be necessary to avoid the anthropogenic impact on nature that cause them (e.g., deforestation, increased wildlife-human contacts, illegal species trade) [7]. However, people's willingness to act tends to decrease if the actions require great personal or social sacrifice [21].

Table 11. Summary of the solutions proposed by the ten groups (shaded in green). The ratio of preventive solutions per group is included to determine their performance.

Code Families	Open Codes	Groups										Total
		A	B	C	D	E	F	G	H	I	J	
Prevent pollution	Use of less toxic biocides											4
	Stop using pesticides											5
	Limit the pesticide use											4
	Test other biocides on animals											1
	Subtotal	2	1	2	1	3	0	1	3	0	1	14
	Ratio (Subtotal/Total)	0.3	0.1	0.3	0.5	0.4	0.0	0.5	0.6	0.0	0.3	-
Mitigate or maintain damage	Migrate to safe areas											4
	Relocate crops at the estuary											3
	Relocate crops in safe areas											3
	Fish in safe areas											3
	Import products from safe areas, do not consume/use polluted products											7
	Detoxify the area and monitor population health											6
	Build a dam											1
	Increase the sentinel organisms' population											1
	Subtotal	5	6	4	1	4	2	1	2	1	2	28
	Total	7	7	6	2	7	2	2	5	1	3	42

According to [48], the opposite is true in media reports, i.e., preventive solutions predominate over palliative ones. They also state that there are more news items that (briefly) expose the consequences of environmental problems than their causes. Hence, it is not surprising that students find it difficult to relate one piece of news to another, seeing them as unconnected, and tend to wait for others (experts) to tell them how to solve problems, rather than coming up with their own ideas.

Other frequent ideas (Table 11) such as crop relocation or human migration would not solve the problem, but only displace it. Even unrealistic actions are proposed. For instance, group A suggests “chlorinate the river to remove pesticides ... okay, it is impossible”, being aware that it is not plausible. Group J proposes “throwing pesticides in the rubbish bin instead of the river”, showing a lack of knowledge about pesticides and considering only the direct route of arrival of pollutants in the water. Strikingly, something similar happens when thinking about how plastic waste ends up polluting the sea [4]. Therefore, a threshold value of content knowledge is also necessary to make a sound argument for the proposed solutions [9].

In short, although all groups follow the same instructions, they behave differently. This could be due to the scenario they face [16] and/or to their intellectual baggage (prior knowledge, values, and past experiences) [23]. In this sense, information on the risk to human health seems to be decisive for most groups (values). Furthermore, some learners propose actions based on their prior knowledge of historical events (Chernobyl disaster). Finally, past experiences do not seem to have influenced the proposed solutions, as students do not relate the problem to their personal lives.

In other studies (e.g., [9]), the SEE-SEP model is used to determine which aspects students focus on when arguing about SSIs. However, in this study, the model is only

considered if students, in addition to proposing solutions to solve the pollution problem, evaluate the impact of their implementation (a non-explicit demand of the activity). In this sense, the groups propose solutions on 42 occasions. The impact of implementing them is only assessed on 11/42 occasions. When doing so, students only apply three perspectives of the SEE-SEP model: economic, environmental, and scientific-health (Table 12). Specifically, the performance of group E is the highest, considering three perspectives, followed by groups B and H that only apply two. Finally, groups A, C, G, and J only assess the plausibility of solutions from a single perspective. The remaining groups (D, F, I) do not evaluate the consequences of their proposed actions (lowest performance).

Table 12. SEE-SEP perspectives applied by the groups when reflecting on the consequences of the solutions (shaded in green).

Perspective	Groups										Total
	A	B	C	D	E	F	G	H	I	J	
Scientific-health											4
Economic											4
Environmental											3
Sociological											0
Ethical											0
Political											0
Total	1	2	1	0	3	0	1	2	0	1	11

Hence, it seems that embracing all perspectives is not easy, and that the ability to “evaluate proposals” is not spontaneous in students’ reasoning. In this regard, [49] argues that only if students are encouraged to do so is their performance likely to improve. However, in the case of “using evidence when arguing” (a skill related to the first phase of the activity), [42] found a similar level of performance between groups that were prompted to use all available evidence and those that were not. Therefore, we believe that rather than making the requirement explicit, the key is to train students to deal appropriately with such tasks and teachers to use thought-provoking questions to guide students’ reasoning.

Regarding the scientific-health perspective, Eve (Group B) understands that if a dam is built at Sun Lance (this proposal shows an ignorance of the water cycle), people living upstream would continue to drink unhealthy water. When group G proposes to relocate the affected population to safe areas, they wonder whether this decision could result in the displaced people “infecting” healthy people. This highlights an alternative idea, the confusion between “pesticide exposure” and “microbial infection”. Earlier in the speech, learners argue the following: “If people drink contaminated water, they could become infected with bacteria. This would cause reproductive problems when they urinate because the bacteria would get into their reproductive organs. And if they have sex, they could infect other people”. Again, the proposed solutions and their assessments are conditioned by the failed attempt to align the data provided in the activity with the students’ prior knowledge, in some cases alternative conceptions (e.g., confusion between reproductive and excretory apparatus).

Groups E and J value the positive impact of their proposals on humans’ reproductive health, applying the concept of “sentinel organism” acquired in the first phase of the activity, and linking human health with that of other animals in the same environment (One Health). For instance, Gunter (group E) recommends “testing different pesticides on flies to see if they affect their reproduction and consequently also that of humans, choosing the least harmful ones”. Moreover, Pauline (group J) suggests “breeding more flies to know if something is wrong because they die (she misinterprets the information) before humans”. In both cases, students only consider the flies’ usefulness as an early danger warning, apparently placing less value on their lives than on human lives. This attitude would be far from the emotional reasoning pattern of [50], characterised by considering the consequences of decisions for other people and species, being responsible for them and desiring their well-being (empathy and sympathy).

Regarding the economic perspective, when Anne (Group A) suggests bringing fish from safe areas, Lucy raises importation as a problem, probably associated with a higher economic cost and/or effort (although not considered, transport would also have an environmental impact, hence the importance of consuming local products). In group C, Gaby also refutes Denisse's proposal to limit the pesticide use: *"If you do not use pesticides, there would be a plague of aphids that would eat everything"*. He seems to be concerned about the economic losses that the solution would bring to the region, prioritising economic interests over environmental and human health (the same reflection is raised by groups E and H).

Considering the environmental perspective, Hans (Group B) proposes relocating crops near the estuary to reduce damage, but pollutants dilution in the sea is not the solution [51]. George agrees with Hans: *"Right, so the water in upstream cities would be pesticide-free"*. However, Eve realises that Hans' proposal would only displace the problem by affecting others: *"If you do that, instead of polluting the river, you pollute the sea. That is fine for you because you eat healthy, but you still pollute"*. Alex (Group E) reflects similarly when assessing Gunter's proposal to move crops to Volantis: *"Although Volantis is not polluted now, if pesticides are used there, it will be"*. In group H, when Nico rejects the idea of stop using pesticides because it would lead to the emergence of bugs (*"Nobody wants to eat bugs"*), Nelly defends the need for bugs (*"They are natural and must be there"*). Nico prioritises his own interests, showing an anthropocentric perspective (nature at the service of humans, to the detriment of the biocentric view), which is a widespread attitude among students [52].

In summary, the results show that most students simply complete the task, without assessing the consequences of their proposed actions, taking responsibility for them, and understanding that some of them are unreasonable. When they do so, it is mainly to refute the solutions proposed by their peers, applying the scientific-health and economic perspectives, followed by the environmental one. Thus, as with the establishment of relationships between data (first phase of the activity), counter-argumentation could be associated with better student performance in proposing solutions. In fact, counter-argumentation involves applying critical thinking to explore different dimensions of a given issue [11]. However, neither group assesses the sociological, ethical, or political implications of their actions. These results are consistent with other studies [9,17], in which students discuss the use of the hydrogen fuel bus and reject or support a ban on fishing for economic, environmental, and scientific reasons, but rarely for ethical, political, or sociological reasons. Therefore, it seems that not all aspects of the SEE-SEP model are equally relevant for students when making and evaluating decisions. Nevertheless, by the design of the task, it is not considered better for students to focus on one factor or another. The expected outcome is the consideration of multiple perspectives when arguing for the solutions they propose, something that groups B, E, and H achieve (Table 12).

4. Conclusions and Educational Implications

Although the results of this study cannot be generalised, they are worth considering, as they show that a short intervention with students who are not used to self-directed group work, nor arguing about SSIs, leads them to practice scientific and environmental skills, as well as communication and teamwork skills (e.g., oral expression, reading literacy, active listening, respect for all opinions). Specifically, the cognitive demand of the activity promotes that students reach the most complex levels of Bloom's taxonomy [53] to solve the tasks: application of knowledge, analysis of information, synthesis of the most relevant ideas, and evaluation of the different options to formulate a well-founded conclusion.

Regarding RQ1, to decide and justify the best option for ranking cities, the designed activity favours evidence-based reasoning without the need for prior mastery of the scientific content. Thus, it encourages students to act as autonomous knowledge producers, finding relevant information (qualitative and quantitative) within the learning environment, interpreting it by considering their theoretical models of reference, and relating a wide range of data to each other (at different scales and on different species), which otherwise

would not have been related (e.g., micronuclei formation in *Chironomus riparius* to pesticide use). This allows them to improve their previous knowledge, acquire new knowledge, and develop their scientific skills. Thus, all groups draw evidence-based conclusions, think critically and experience uncertainty in decision-making. Moreover, all groups try, and many succeed, in formulating valid causal explanations for ranking cities, but only after understanding the relevance of each piece of information provided in the response.

Considering RQ2, when proposing solutions and assessing their impact, students also develop their environmental knowledge and skills. Thus, they learn and apply new concepts (e.g., sentinel organism). Furthermore, they are more aware of the causes of environmental pollution and its health consequences (One Health). They are also involved in proposing solutions to curb the problem, although they are predominantly palliative (short-term) at the regional level, and respond mainly to human interests. Some students even evaluate the impact that the actions proposed by their peers could have (group responsibility) from scientific-health, economic, and environmental perspectives. However, a holistic view of the complexity of environmental problems is not achieved and this may be due to the fact that ethical, political, or sociological aspects are not being given importance in science classes. In any case, the aim of the task is fulfilled, as the expected outcome is not that learners end up proposing particular solutions, evaluating them in a certain way, or changing their behaviour, but that they understand that environmental SSIs should be addressed with open-mindedness and a predisposition to critical thinking. Furthermore, even if proposing solutions is not seen as taking action, if students feel that their opinion matters and that it is not a one-off action imposed by the teacher (e.g., cleaning up a polluted space), they are more likely to adopt pro-environmental behaviours in the future.

In sum, the results of this study pose global challenges for activity design in the 21st century, which complement international calls to promote the development of reasoning skills on SSIs related to environment and health [33,54], thus bridging the gap between research and educational practice [55]. Therefore, we suggest that science teachers should do the following: promote learning environments in which different semiotic modalities must be interpreted with sufficient scepticism, as science is inherently multimodal and not all sources of information are reliable; encourage teamwork and argumentation on authentic problems; reinforce students' emotional reasoning and not only logical/scientific reasoning, ensuring in both cases their quality; address the health of the planet and its inhabitants as unique; use interdisciplinary educational approaches to address environmental problems holistically, reinforcing the relationship between visible (macroscopic) and invisible (microscopic) causes and effects; and promote the proposal of reasoned solutions, trying to bring all actors involved in the solution into agreement.

Such challenging learning experiences need to become standard classroom practice (the norm rather than the exception), preferably addressing scenarios close to the students (e.g., the problem of drought in fire-prone areas), in which they feel useful [30,56]. This could be the springboard for action, within the framework of quality environmental education and not only focused on conceptual learning [2]. However, this requires better teacher training, both to deal with such activities and to select or design scenarios to be applied in their classrooms [10].

For future research, the activity could help to introduce the SDGs in the biology classroom (e.g., SDG 3: health and well-being, SDG 6: clean water and sanitation) and to understand the complexity of managing environmental challenges, reflecting on the inequalities that exist in addressing the same problems in different parts of the world [20,57]. In this sense, contributing through education to sustainability, as well as social and environmental justice, is essential if the health of living beings is to be guaranteed [3,52].

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/su15086984/s1>, News S1: Facebook news provided to students; Report S1: Technical report provided to students; Table S1: Summary of the data provided in the first phase of the activity on the causes and effects of the pollution problem.

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