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A Toolbox for Integrating the One Health Approach Into Biology Teacher Training

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Abstract

This study advocates integrating the One Health approach into biology teacher education to address the current fragmentation of human, animal, and environmental health teaching across disciplines such as medicine, veterinary science, and ecology. Recognizing gaps in teacher training, particularly in didactic strategies for holistic instruction, the study presents the design of an instructional activity within the expanding *One Health toolbox* for biology educators. Using mitosis as a gateway topic, the activity situates cellular processes within an ecotoxicology scenario of herbicide contamination in a freshwater lagoon. Through inquiry, modeling, and argumentation, pre-service teachers investigate environmental, animal, and human health interconnections while reflecting on strategies for classroom integration. This design aims to strengthen biology teacher competencies (*TeachComp*) and contribute to reorienting teacher education towards sustainability, fostering eco-social awareness and interdisciplinary thinking essential for addressing contemporary health and environmental crises.

Keywords: Action research, biology education, mitosis, One Health, teacher education, toxicology.

Introduction

The concept of One Health, while gaining momentum in scientific research and education today, is far from new. Its formal origins date back to the early 2000s, when the Manhattan Principles were formulated to prevent epidemic and epizootic diseases while preserving ecosystem integrity to benefit humans, domesticated animals, and the foundational biodiversity that sustains life (Cook et al., 2004). Later, the movement expanded internationally thanks to a tripartite agreement between the Food and Agriculture Organization of the United Nations (FAO), the World Health Organization (WHO), and the World Organization for Animal Health (WOAH, founded as OIE) to share responsibilities and coordinate global activities to address health risks at the animal–human–environment interfaces (WHO, 2010), mainly in the field of public health and veterinary medicine. In this sense, One Health acknowledges the interconnectedness of human, animal, and environmental health, emphasizing this framework in response to increasingly complex health challenges that transcend these three dimensions (Amuasi et al., 2020). For instance, the growing impact of environmental degradation, such as pollution, biodiversity loss, and disruptions in the food web, affects the health of organisms within the ecosystem. This includes the emergence of diseases, such as zoonotic ones, which are transmitted from animals to humans (Schmeller et al., 2020). Similarly, environmental pollution caused by pharmaceuticals and the improper use of medications is leading to an increase in antimicrobial resistance. This situation affects both animal and human health, underscoring the urgency of systemic responses (Wilkinson et al., 2022).

Historically, to mitigate public health risks within the One Health framework, biosanitary tools from ecotoxicology and epidemiology have primarily been used, focusing on the impacts of pollutants and diseases on organisms and ecosystems (Barrett et al., 2011; Ogunseitan, 2022). At its core, the approach emphasizes integrating human, animal, and environmental health through collaborative frameworks where community participation is key to success (Mitchell et al., 2022). However, community engagement often occurs reactively (Barrett et al., 2011; Ogunseitan, 2022), triggered by crises such as disease outbreaks or environmental disasters (events that are often interlinked). When such crises arise, experts and authorities guide communities on necessary response measures through information (Sahani et al., 2024), but the focus on immediate action often means that educating or training citizens proactively is overlooked. This reactive approach misses valuable opportunities for prevention through education (Pérez-Martín & Esquivel-Martín, 2024), leaving communities unprepared for future health threats. Thus, building a proactive One Health approach centered on prevention requires full integration into civic education from early stages to teacher preparation, promoting lasting, effective community engagement (Barrett et al., 2011).

Reflecting this shift, the One Health approach is increasingly prominent in educational frameworks. A significant milestone occurred in 2015 when the One Health Commission established the One Health Education Task Force (OHETF), aiming to promote One Health education globally. This initiative led to the development and publication of educational materials designed to make the One Health concept accessible to teachers and students at multiple educational levels. In 2016, the OHETF released a conceptual framework advocating for a global One Health education program (Lueddeke et al., 2016). This program was designed to integrate One Health principles directly into conventional curricula worldwide, advancing the inclusion of this interdisciplinary approach across diverse educational contexts.

This curricular inclusion at the international level has been accomplished, as demonstrated by its recent incorporation into the Spanish educational curriculum following the enactment of the new education law (LOMLOE) in 2020, implemented from 2022. This reform places significant emphasis on knowledge and skills related to eco-social awareness and One Health, both terms that had not been explicitly stated in the curricula previously (Martínez-Pena et al., 2024). In sum, it aims to underscore the importance of preparing students to address global issues with a systemic view, considering the complexity of these challenges and their own role both as contributors to the problems (through daily choices) and as potential contributors to solutions (McAlister et al., 2022).

Yet, despite such initiatives aimed at disseminating resources to promote the implementation of this approach in science classrooms, there are few proposals in the literature to put it into practice (Haxton et al., 2015; Pérez-Martín & Esquivel-Martín, 2024), something that teachers demand to work on issues related to environmental health (Mora-Penagos & Guerrero-Guevara, 2022). This limits the application of the One Health approach in classrooms (Barrett et al., 2011; Humboldt-Dachroeden, 2023).

Furthermore, despite the curricular and theoretical emphasis on the interconnectedness and interdependence of human, animal, and environmental health, the One Health approach is generally implemented in a fragmented manner when this content is addressed, typically within specialized training for medical, veterinary, and environmental science professionals (Mackenzie & Jeggo, 2019). In fact, each discipline tends to incorporate aspects of One Health most relevant to its field without necessarily adopting an interdisciplinary vision that considers all involved sectors (Barrett et al., 2011). Recent studies (e.g., Barrett et al., 2011; Pérez-Martín & Esquivel-Martín, 2024) identify this compartmentalized approach as an obstacle to effectively implementing the One Health model in classrooms, as this fragmentation extends to the training of future educators. For example, Spanish secondary science teachers come from disciplinary backgrounds (e.g., biology) and must subsequently obtain a Master's degree to become qualified to teach. Consequently, their understanding of the One Health approach primarily stems from their disciplinary training, which is fragmented, as mentioned above.

Therefore, many specialists and educators lack the comprehensive training to deliver One Health concepts and principles cohesively in classrooms. Instead, these concepts are presented as isolated disciplinary knowledge, hindering a holistic understanding and development of interdisciplinary skills among students. For this to change, a fully integrated curricular approach to One Health in teacher training would be far more effective (Haxton et al., 2015). This would involve building connections between disciplinary knowledge (e.g., biology, ecology, and health sciences) with robust pedagogical/didactic content knowledge, enabling educators to integrate these domains meaningfully (Pérez-Martín & Esquivel-Martín, 2024).

This gap in teaching competency, hereafter referred to as *TeachComp* (a term we propose, drawing on European frameworks for teacher competencies), highlights the need for specialized training to equip future educators with skills that go beyond isolated scientific knowledge disconnected from everyday life (Walker, 2017). These educators should foster critical thinking and responsibility, empowering future generations to actively address local and global issues such as climate change, biodiversity loss, and pandemic prevention (McAlister et al., 2022; Organisation for Economic Co-operation and Development [OECD], 2023; Schmeller, 2020).

In the present study, we focus on training high school educators in transformative approaches to environmental health education (Reid et al., 2021). This initiative aligns with recent curriculum requirements and addresses the growing need for 21st-century citizens to gain tools for addressing these issues in informed, proactive ways. However, adequate methodologies and resources for such teaching are not always readily available (Guevara-Herrero et al., 2023; Roldán-Arcos et al., 2022). For this reason, it is crucial to prepare future educators to integrate eco-social and One Health-focused environmental education into their classrooms, fostering interdisciplinary perspectives and professional competence (Haxton et al., 2015).

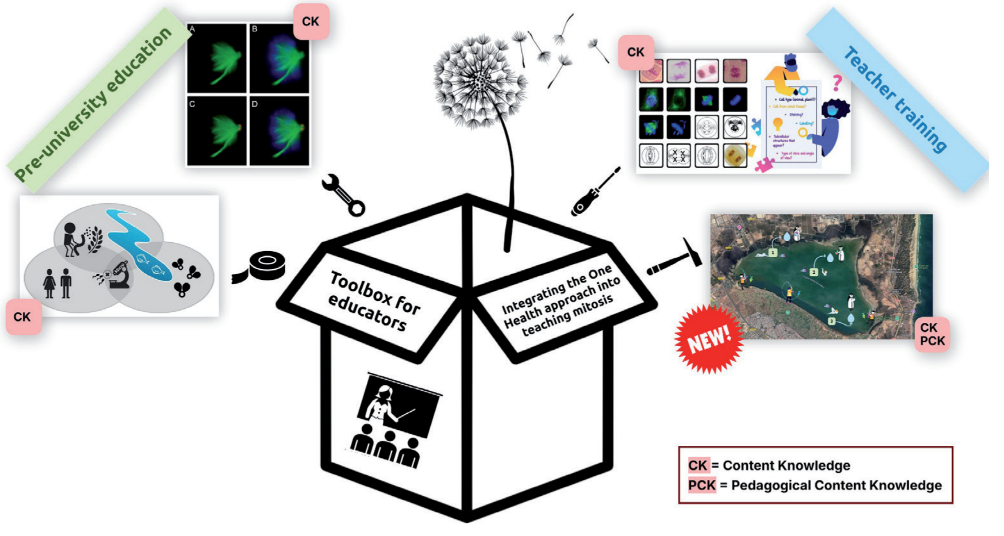
Building on previous research by our team (Esquivel-Martín, Bravo-Torija & Pérez-Martín, 2023; Esquivel-Martín, Pérez-Martín & Bravo-Torija, 2023), we approach this challenge through a research-action lens, co-developing resources with and for pre-service teachers to link core biological processes, such as cell division, to real-world environmental and health issues. Thus, the objective of this study is to design an activity to integrate the One Health approach into teacher training classrooms. For this purpose, the topic of cell division has been selected, as it illustrates how cells interact with their environment and respond to environmental stressors such as pollutants (Herrero et al., 2012). By understanding cell division, pre-service teachers can grasp biological processes essential to organismal health and homeostasis, such as cellular reproduction, tissue repair, growth, and renewal. These processes are vulnerable to environmental factors like toxic exposure, which can have far-reaching consequences for life (Pérez-Martín et al., 2008). The deterioration of ecosystem health can disrupt mitosis and meiosis, resulting in illnesses like cancer and reproductive disorders that affect both human and animal health, highlighting the interdependence of health across all dimensions.

Extensive research has documented the challenges in teaching and learning about cell division (Dikmenli, 2010; Rodríguez et al., 2019), making it difficult to develop a deep understanding of how environmental pollutants influence organismal health. To address these difficulties, the case method has proven effective in enhancing students' scientific and environmental competencies, as shown in prior studies by the research team (Esquivel-Martín, Bravo-Torija & Pérez-Martín, 2023; Esquivel-Martín, Pérez-Martín & Bravo-Torija, 2023). In these studies, tenth-grade students tackled challenges related to cancer and reproductive health in different organisms, resolving them by applying their models of mitosis and meiosis. Both studies underscored the importance of allowing students to build, evaluate, and refine their cell division models in realistic contexts that encourage connections between environmental, animal, and human health data. The findings demonstrated an increased sophistication in students' understanding of cell division and in their systemic view of health (One Health).

These previous studies form part of an educational toolbox (Figure 1) that promotes science teaching based on scientific practices such as argumentation, inquiry, and modeling (National Research Council [NRC], 2013; OECD, 2023).

Figure 1

Toolbox for Biology Teachers Integrating the One Health Approach Into Teaching Mitosis. It consists of four activities (including the one presented in this article) designed to enhance both students' and teachers' content knowledge (CK) and teachers' pedagogical content knowledge (PCK) of cell division.



This toolbox promotes critical thinking and a systemic understanding of One Health within the context of Environmental Education, as advocated by various authors such as McAlister et al. (2022). Additionally, it is complemented by digital materials featuring diagrams, three-dimensional animations and micrographs of the cell division process (Esquivel-Martín et al., 2024), with real images being rarely used in the teaching of this content (Shelden et al., 2019). These materials are designed to aid teachers in session preparation, supporting both their professional development and their content knowledge. In this work, the toolbox is extended with a new activity to facilitate the understanding of effective teaching strategies in science education (PCK) (Figure 1).

Method

This study is framed within a broader action research project aimed at integrating the One Health approach into secondary biology teacher education. The overall project follows the classic action research cycle (Kemmis & McTaggart, 2005):

1. Diagnosis: Identifying gaps in pre-service biology teachers' ability to connect cellular biology concepts with environmental and public health issues.
2. Planning: Co-designing activities that bridge disciplinary content and sustainability challenges.
3. Action: Implementing the designed activities in authentic educational settings.
4. Reflection and Revision: Analyzing outcomes, gathering feedback, and refining the toolbox.

The specific activity presented here, linking mitosis to an ecotoxicological scenario, has been fully developed during the "planning phase" but has not yet entered the "action phase" with pre-service teachers. It is intended for use in a secondary science teacher training course at a Spanish university, where participants have foundational cell biology knowledge but limited exposure to One Health perspectives. While this activity has not been trialed in that context, other activities from the same *One Health toolbox* have been implemented in secondary education, providing valuable precedents for design, facilitation, and reflection.

Activity Design

For the design of the activity presented in this study, we followed the didactic transposition process (Esquivel-Martín et al., 2021; Tiberghien et al., 2009) to adapt reference scientific knowledge into teachable content. Specifically, we transformed key concepts related to cell division, a fundamental and recurrent topic in biology education, into an instructional activity designed for pre-service biology teacher training.

To structure this transformation, we employed the case-based teaching and learning method (Günther et al., 2019), aiming to simultaneously enhance CK (mitosis and One Health) and PCK related to these topics. This approach fosters active learning by positioning participants at the center of the learning process, promoting autonomy and engagement.

The digital version of the open-access activity (Freshwater Lagoon Case) incorporates scaffolding mechanisms and mediating questions to support the development of scientific arguments and encourage evidence-based reasoning. Moreover, instructor facilitation plays a key role in guiding case resolution, ensuring that students integrate conceptual understanding with pedagogical strategies. This structured approach aligns with best practices in biology education research (Scott et al., 2020), making the activity adaptable for diverse educational settings.

The resulting scenario focuses on a freshwater lagoon contaminated by herbicides, where initial *in vitro* assays on cultured cells revealed anomalies in the mitotic process, later corroborated by observations in organisms inhabiting or frequenting the lagoon.

The planned tasks include:

- Analyzing mitotic data from cells exposed to herbicides and interpreting their biological significance.
- Linking cellular alterations to broader ecological, animal, and human health concerns.
- Proposing sustainability-oriented interventions.
- Reflecting on strategies to adapt this case for secondary science classrooms.

Action Research Integration

Although the "action phase" for this specific activity has not been conducted, it is conceived to fit within the iterative action research process:

- Participants as co-researchers: In future implementation, pre-service teachers will contribute to refining the activity and generating context-specific adaptations.
- Iterative development: Insights from previous secondary education-level implementations of other toolbox activities already inform the current design and will serve as a reference for later refinement.
- Sustainability connections: Reflection prompts explicitly address ecological, social, and ethical dimensions, ensuring that disciplinary learning is embedded in a holistic sustainability framework.

From an action research perspective, the current stage corresponds to the "planning phase", enriched by reflective input from past implementations at different educational levels. This approach aligns with the iterative nature of action research, where knowledge generated in one cycle informs the design of subsequent interventions in new contexts. Data collection, once the activity is implemented, will combine qualitative and quantitative approaches: observation notes, pre- and post-activity questionnaires, and written reflections from participants. This evidence will guide subsequent revisions, emphasizing action research as a transformative approach to teacher education.

Results

The primary outcome of this study is the design of a digital, scenario-based activity aimed at integrating the One Health approach into pre-service biology teacher education through the study of mitosis.

The activity simulates a realistic environmental health investigation inspired by reports of a herbicide-contaminated freshwater lagoon. All datasets, images, and prompts have been designed to authentically represent ecotoxicological research without presenting original experimental data from this project. The design aims to scaffold both scientific reasoning and pedagogical reflection, enabling trainee teachers to bridge cellular biology with environmental and public health considerations.

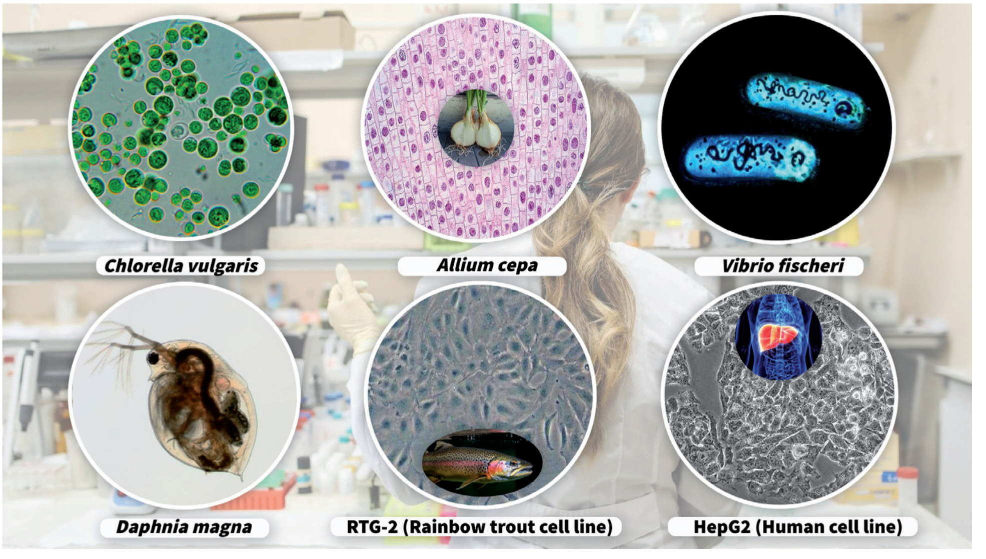
The activity is structured into three phases (Freshwater Lagoon Case: https://view.genially.com/6706f00c9b0bc28ca4d5f884). After answering each question, the digital tool allows you to see the reference answer, which can be self-evaluated.

The First Phase (Ecotoxicology – Toxic Effects)

In the first phase, students have to investigate the effects of polluted water exposure from three different sampling points in the lagoon on six toxicological models (Figure 2) in the laboratory.

Figure 2

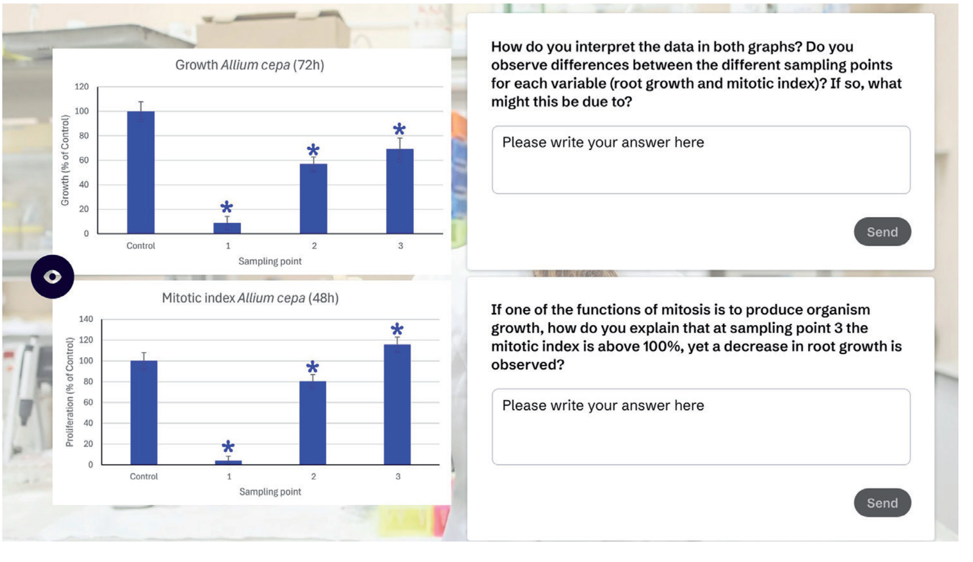
Sample Image From the Digital Activity Showing the Six Toxicological Models, Divided Into Producers (Chlorella vulgaris and Allium cepa), Consumers (Daphnia magna, rainbow trout, and humans), and Decomposers (Vibrio fischeri)



Pre-service teachers should analyze realistic graphs on different toxicological endpoints, interpreting effects on model systems in relation to the controls to establish cause-effect relationships between contaminant exposure and cellular consequences. To collect their arguments, the activity incorporates several questions associated with each model system (Figure 3).

Figure 3

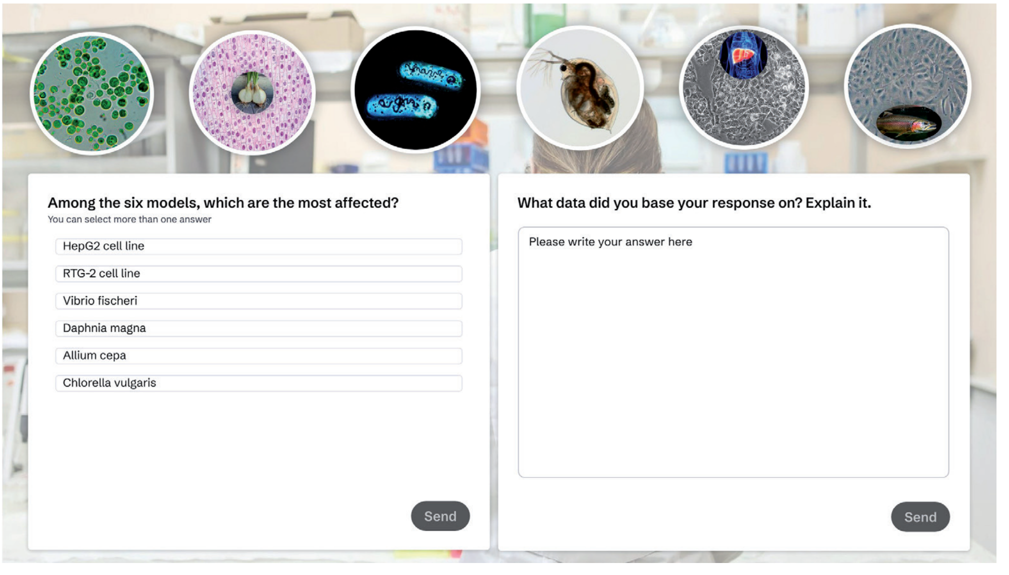
Sample Image From the Digital Activity Showing the Questions Associated With the Allium Cepa Plant Model System in the First Phase of the Activity



The ultimate aim is for trainee teachers to realize that the most affected model systems are the producers, given their limited growth. This, coupled with the fact that the most affected sampling point is the one closest to the crop fields surrounding the lagoon, should lead them to hypothesize that the pollution may come from herbicides (Figure 4).

Figure 4

Sample Image From the Digital Activity Displaying Questions That Transition Students From Phase 1 to Phase 2, in Which They Have to Justify Their Hypotheses About the Toxic Substance Polluting the Lagoon

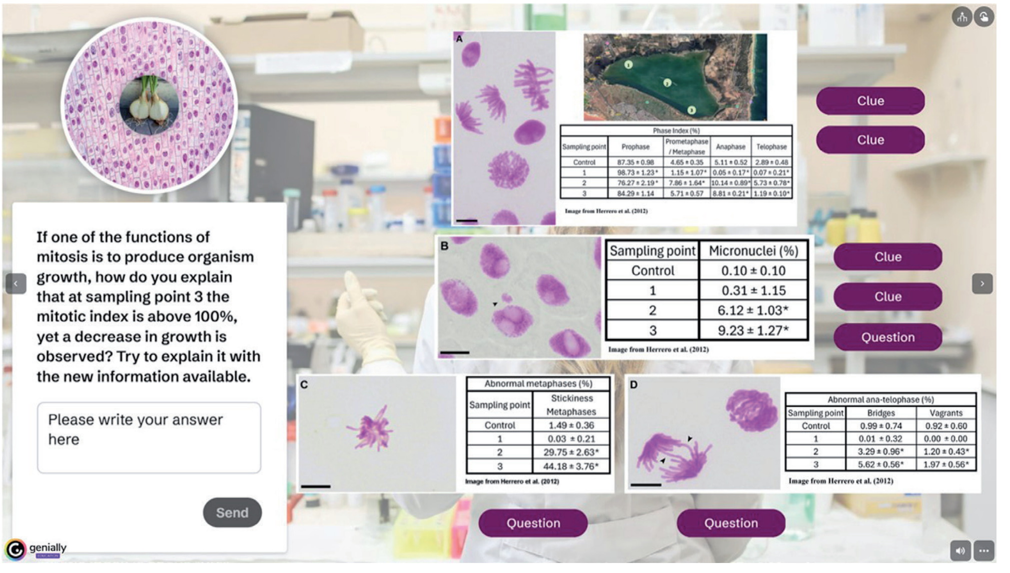


The Second Phase (Ecotoxicology – Mechanism of Toxic Action, Genotoxicity)

The above hypothesis invites to analyze the mechanism of toxic action causing this situation in the producers. To this end, mitosis in onion root meristems is examined to identify the problem. Trainee teachers are provided with data on the mitotic phase index associated with each sampling point, showing difficulties in completing the cell cycle and highlighting the potential genotoxicity of the herbicides in plant cells (Rashid et al., 2022). Data on DNA damage in *Allium cepa* root cells exposed to the water from all three sampling points are also shown: stickiness at metaphase, bridges, vagrant fragments of chromosomes, and micronuclei (with all being interconnected). These results should be combined with the data on root growth at each area of the lagoon and on the mitotic index obtained in the first phase of the activity to answer the question that allows the activity to proceed (Figure 5).

Figure 5

Sample Image From the Second Phase of the Digital Activity (Data Tables, Clues and Questions)



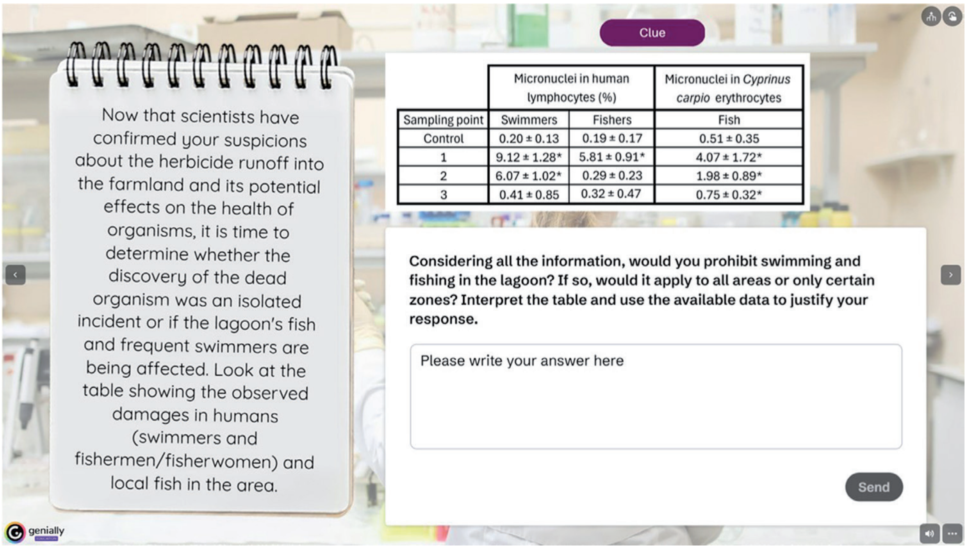
Moreover, at this point, participants are asked to distinguish between clastogenic and aneugenic damage, identifying which type is reflected in the data tables (clastogenic).

The Third Phase (Test on Organisms Inhabiting or Frequenting the Lagoon)

All of the above should lead pre-service teachers to question what happens to the actual animals and humans that inhabit or frequent the lagoon. For this reason, the third phase of the activity addresses the problem of environmental toxicology (environmental mutagenesis) by narrowing down the cellular targets, focusing on mitosis but considering the entire process of the cell cycle. In particular, the activity provides data (genotoxicity effects) on fishes that live in the lagoon, and people who frequent it (swimmers), or feed on the fish caught in it (fishermen/fisherwomen). These data help understand that, in addition to genotoxic damage from direct exposure to water in the lagoon containing accumulated herbicides, there could be a risk of toxicity from long-term or repeated-dose exposure if the people consume animals living in it (Figure 6).

Figure 6

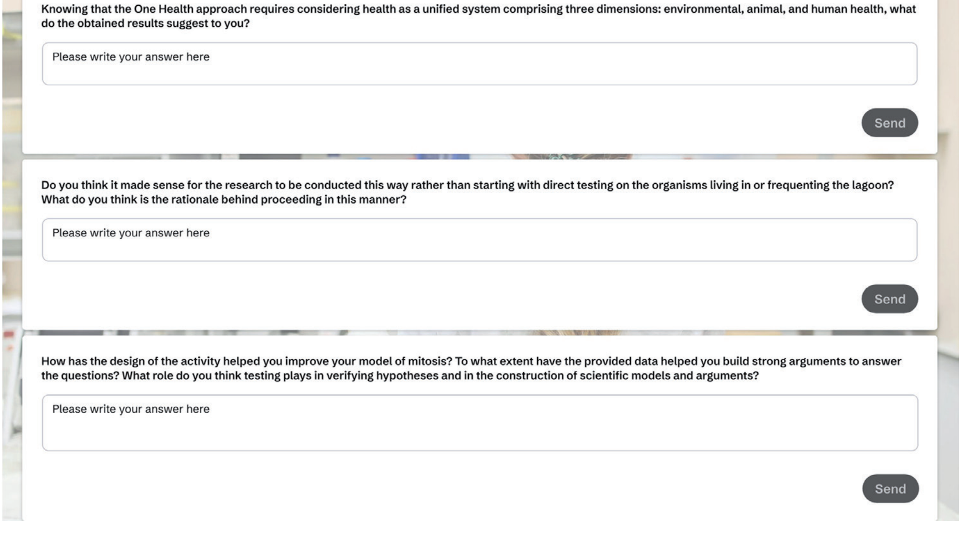
Sample Image From the Third Phase of the Digital Activity (Text, Data Table, Clue, and Question)



Finally, besides enhancing scientific practices like modeling and argumentation, this activity has a valuable epistemic practice component. It encourages participants to reflect on: a) the purpose of each step and material provided, b) the role of evidence in building scientific knowledge, and c) strategies for adapting the case to secondary classrooms, linking observable data with underlying scientific and educational principles (Figure 7).

Figure 7

Sample Image of the Digital Activity Showing the Questions Associated With Trainee Teachers' Exploration of Epistemic and Didactic Knowledge, Reflecting on the Meaning of the Activity Design



Relationship Between the Activity and Each Dimension of One Health

The activity connects the three dimensions of One Health by allowing students to examine (realistically simulated) test results conducted in the laboratory on six different model systems.

In respect of the *Environmental Dimension*, the activity explores how the presence of herbicides in the lagoon directly affects water quality and its ecosystem. Ecotoxicology tests with organisms like *Chlorella vulgaris* (algae), *Allium cepa* (plant), or *Vibrio fischeri* (bacteria) measure the impact of these contaminants on growth or cell viability, helping estimate environmental toxicity levels and disruptive potential on producers and decomposers from aquatic ecosystems. This reflects the interdependence perspective, as all organisms within or relying on these ecosystems are impacted.

Considering the *Consumer's Dimension (Animal Health)*, the impact of runoff from a mixture of herbicides on *Daphnia magna*, a key organism in the aquatic food web, could allow us to infer how contamination might affect animals that depend on these organisms for food (e.g., biomagnification). The same applies to the toxicity detected in other aquatic species, such as fish (e.g., rainbow trout, RTG-2 cell line), which can bioaccumulate toxins like herbicides (Tyohemba et al., 2021), posing risks to human health (e.g., cancer, endocrine disruption, and developmental issues) through frequent consumption.

Finally, regarding the *Human Health Dimension*, the impact is examined by considering local residents and swimmers in contact with the lagoon's water. Basal cytotoxicity studies applying human cell models, such as HepG2, are used to detect potential toxic effects in humans. As Rudolf Virchow famously stated, diseases originate from alterations in the physiology of the cells within a tissue or organ. Furthermore, observations on how herbicides may induce micronuclei formation in human lymphocytes highlight potential genotoxic effects (Nagy et al., 2019), reflecting long-term health risks for exposed humans.

Relationship Between the Activity and the European Competency Framework

The activity allows trainee teachers to develop three of the European Competency Framework's key competencies: DigComp (Punie & Redecker, 2017), LifeComp (Sala et al., 2020), and GreenComp (Bianchi et al., 2022). The nexus of all of them is that collaborative and self-regulated learning takes place, supported by the designed materials (scaffolding) that accompany the practical cases.

In terms of DigComp (Digital Competency), the activity encourages trainee teachers to effectively engage with multimodal online resources, data tables, and visual aids, collaborating on digital platforms to share findings, discuss hypotheses, and critically evaluate arguments based on available data. This prepares teachers to apply technology and digital resources to tackle complex, cross-cutting problems in the classroom.

For LifeComp (Life Competency), the activity fosters the ability to identify complex problems requiring the processing and integration of extensive information and applying suitable scientific models to propose reasoned solutions. Furthermore, it encourages pre-service teachers to develop critical thinking (evaluating information and arguments to reach reasoned conclusions and devise innovative solutions) and to communicate within a specific context where they must deal with uncertainty, as there is no obvious or immediate answer (learning to learn).

Finally, regarding GreenComp (Environmental Competency), the activity aims to foster eco-social awareness by examining the impact of pollution on swimmers' health and the health of other organisms. It encourages discussions on public health and environmental preservation, sensitizing future teachers to social and cultural issues affecting their communities. The ultimate goal is to promote responsible action in response to environmental issues by understanding their causes and consequences, reflecting on possible non-standardized solutions (rather than those conveyed by others), and, above all, recognizing the importance of bringing these topics into the classroom, which is their primary vehicle for impact ("Dandelion approach").

Discussion and Conclusions

This study contributes to the ongoing reorientation of teacher education towards sustainability by embedding the One Health framework into biology teacher training. Implementing One Health effectively in schools requires teachers who are not only scientifically competent but also committed to sustainability as a guiding principle of their practice (Barrett et al., 2011; Pérez-Martín & Esquivel-Martín, 2024). This work contributes to that vision by extending a toolbox that blends biological content, ecotoxicological awareness, and pedagogical strategies within a research-action framework. Developed from our direct experience with pre-service biology teachers, the activity fosters critical reflection on how health, environment, and society are interlinked, while equipping educators to integrate these dimensions into authentic, community-relevant science education. We pursue this goal because teacher training in areas such as environmental education, One Health, and even foundational topics like mitosis is often limited or incomplete, both in terms of CK and PCK (Dikmenli, 2010; Şen et al., 2018).

To address these gaps, the designed activity positions pre-service teachers as active participants in an authentic investigation, where they must interpret ecotoxicological data, link cellular and ecosystem health, and critically evaluate human impacts. This experiential approach reflects a research-action ethos, where teaching resources are not static products but tools for iterative learning, reflection, and adaptation. Moreover, the designed activity employs multimodal scaffolding, combining diverse forms of presenting complementary and interconnected information (e.g., images, tables, graphs, and text) to convey information on the problem and content related to cell division, ecotoxicology and their relationship with One Health. This promotes a more holistic understanding of those scientific models, as participants should use the characteristics of each modality for meaning making (Esquivel-Martín et al., 2024; Jaipal, 2009). Although the activity has not yet been implemented in the intended teacher education context, its design draws on empirical precedents from lower secondary settings, where other toolbox components have been successfully trialed. These earlier experiences have shown that connecting microscopic processes to broader ecological and health implications enhances student engagement, fosters systems thinking, and supports the integration of sustainability into science learning.

Thus, from our own experience developing and testing this toolbox, we have observed how connecting cell division to urgent, real-world issues transforms pre-service teachers' engagement. They move from viewing mitosis as an isolated biological process to understanding it as part of a complex system in which environmental degradation can alter fundamental life mechanisms, with cascading consequences for ecosystems and societies. This shift (towards systemic and preventive thinking) is precisely what sustainable education seeks to cultivate.

The activity reinforces professional competencies aligned with European frameworks (*DigComp*, *LifeComp*, *GreenComp*), encouraging teachers to integrate digital tools, manage complex problem-solving, and promote eco-social responsibility. Importantly, the case-based structure and multimodal scaffolding support both disciplinary mastery and pedagogical reflection, strengthening *TeachComp,* which encompasses teachers' knowledge, teaching methods, experience, and integration of validated educational research into their practice.

Furthermore, two dimensions of sustainability are particularly reinforced here. First, environmental sustainability is advanced through the emphasis on ethical, non-animal testing methods aligned with the 3Rs (Reduction, Refinement, and Replacement) in animal research (Russell & Burch, 1959), thereby modeling how scientific inquiry can be both rigorous and responsible. Specifically, it supports the Replacement Principle by promoting in vitro methods as alternatives to animal testing, directing further research only towards the organisms most affected, particularly those showing higher cytotoxic or genotoxic damage. This dual-level evidence base (*in vitro* and *in vivo* components) not only reinforces the biological CK but also provides a platform for discussing research ethics, methodological choices, and the role of empirical evidence in addressing sustainability challenges.

Second, social sustainability is strengthened by fostering educators who are prepared to address community-relevant issues, thus empowering students to act as informed citizens in the face of local and global health challenges. In relation to this, scientific research findings are rarely connected to educational content in classrooms, except in occasional instances (e.g., Domènech-Casal 2016). However, in this activity, the pre-service educators are required to constantly compare results across different tests and analyze whether significant differences exist between them. In fact, the activity explicitly highlights the significant differences between the variables analyzed at each sampling point in the lagoon compared to the control. Nevertheless, it does not provide data to estimate whether the observed differences across the different exposure times are significant. In this sense, it is expected that future teachers will recognize the need to assess the significance of the data (statistics). This is relevant because toxic effects can vary in both intensity and persistence, and the sampling location and exposure time are key factors in assessing environmental risk.

In general, the activity empowers pre-service teachers in two ways: by reinforcing and deepening their understanding of mitosis and One Health (enriching their conceptual models of them) and by helping them grasp how the activity is structured from a didactic perspective (i.e., structure, materials, mediating questions, and cognitive demand).

The above is essential for promoting transformative teaching (Reid et al., 2021). Therefore, this initiative seeks to improve teachers' perception of self-efficacy as well as to motivate them to create activities that foster critical thinking and promote interdisciplinary knowledge in realistic contexts. Thus, while the current implementation is context-specific, its design is adaptable across curricula and cultural settings, inviting future research on its application in diverse socio-ecological contexts. The broader goal is not merely to teach biology content more effectively, but to cultivate educators capable of inspiring proactive, sustainability-oriented mindsets in their students (a "dandelion effect", Figure 1) where knowledge and responsibility disperse far beyond the classroom. This could improve biological education, fostering scientific vocations among future scientists and, more broadly, cultivating an informed citizenry capable of making decisions and taking actions grounded in sound judgment.

Ultimately, reorienting teacher education towards One Health is about more than integrating new content: it is about fostering a generation of educators, and through them, citizens, who can recognize early warning signs, understand interconnected risks, and take preventive action. This study offers one pathway toward that vision, grounded in the belief that sustainability begins with informed, empowered teachers.

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