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SYSTEMS THINKING (ST) ON COMPLEX HEALTH ISSUES: THE APPLICATION OF THE ONE HEALTH (OH) APPROACH

Inés Martinez Pena,
Blanca Puig,
Araitz Uskola

Abstract. *Systems thinking (ST) is an essential skill for understanding complex issues, making predictions and informed decisions. This research explores how students applied ST in complex health contexts using the 'One Health' (OH) approach. OH highlights the interdependence relationship between animal, human and ecosystemic health (including plants). Eighteen upper secondary school students were involved in activities that aimed to foster their capacity to apply ST to explain the causes of the COVID-19 pandemic, to anticipate future pandemics and to propose actions for preventing them. Individual written tasks were examined using content analysis methods. Four dimensions of ST were considered, and levels were established based on the literature and in interaction with data. Most participants articulated various aspects of ST in their responses, but they did not do so consistently. Students had difficulties both in anticipating future pandemics and in proposing actions to prevent them. After the completion of the activities, most students showed an improved understanding of the OH notion. They identified the components, relationships and provided examples of causal interrelationships, such as those involved in zoonotic diseases. The findings point to the potential of the OH approach in Biology education, as it promotes students' understanding of complex health issues from a systemic view.*

Keywords: *COVID-19 pandemic, interpretative study, one health, systems thinking, zoonosis*

Inés Martinez Pena, Blanca Puig
University of Santiago de Compostela (USC), Spain
Araitz Uskola
University of the Basque Country UPV/EHU, Spain

Introduction

Many health issues are "systemic problems" that affect human, environment and animal health; thus, their understanding might benefit from the integration of the 'One Health' (OH) approach in Biology education. The United Nations Environment Assembly that took place in 2022 recognized the risk of future pandemics and other health concerns. This risk is fostered if humans do not revise their patterns of interaction with nature by adopting a holistic approach such as OH (Food and Agriculture Organization of the United Nations [FAO] et al., 2019; FAO et al., 2022). OH takes into account the interrelationships between the health of animals, ecosystems and humans.

Thus, Biology education, in line with all disciplines forming school curricula, should promote students' development of systems thinking (ST) as part of their health literacy to take actions that benefit them, the community and the planet. The World Health Organization (WHO, 2021) provided the following definition of health literacy:

> "Health literacy represents the personal knowledge and competencies that accumulate through daily activities, social interactions and across generations. Personal knowledge and competencies are mediated by the organizational structures and availability of resources that enable people to access, understand, appraise, and use information and services in ways that promote and maintain good health and well-being for themselves and those around them" (p.6).

Even though the notion of OH has been around for some time in the scientific community and political institutions, it is only recently gaining momentum in the public eye regarding the teaching of Biology. In Biology education, there are few studies that address the OH approach (Uskola & Puig, 2022) particularly in teaching and learning complex health issues, even though the COVID-19 pandemic has highlighted the importance of promoting the application of OH to understand these problems from an integrated viewpoint (Byrne et al., 2022; Rönner et al., 2023a, 2023b).

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The current Biology curriculum for secondary education in Spain, aligned with the Sustainable Development Goals (SDGs) proposed by the United Nations (United Nations, 2015), supports incorporating OH in Biology education. However, teachers are not being provided with tools or examples of learning situations that can help to engage students in its application to real-life contexts. This study advocates that ST is necessary to understand the OH notion, as ST has helped to address the linear and reductionist approaches that prevail in health problems (Atun, 2012) and comprehend the factors that interact and influence the complexity of these issues.

The Integration of the 'One Health' (OH) Approach in Health Literacy

The COVID-19 pandemic evinced that we live in a globalised world, where human public health problems are no longer restricted to specific geographical areas and that our health is closely related to animal and environmental health. This global view is required to improve students' health literacy. From today's health literacy perspective, social, economic, and environmental issues become as important as individual factors. Nutbeam (2000) distinguished between functional health literacy, interactive health literacy, and critical health literacy. Functional health literacy consists of providing information about risks and about health systems; interactive health literacy focuses on generating motivation and self-confidence; critical health literacy seeks social and political action in addition to individual action. The need for actions is particularly relevant in the context of health education and was taken into account by the Organization for Economic Co-operation Development (OECD) in the definition of the Learning Compass 2030 (OECD, 2018) that aims to help students to navigate towards future well-being. As Levrini et al. (2020) suggested, agency and awareness of the need to take responsible actions emerge through anticipatory and reflective processes, and perception of the future involves personal engagement (Levrini et al., 2015).

The definition given by WHO (2021) mentioned above, is coherent with the critical view, but does not include references to animal nor environmental health, dimensions included in the OH notion, in spite of the fact that OH was introduced at the beginning of this century. OH was established by the OH High-Level Expert Panel, and it recognizes that the health of humans, domestic and wild animals, and the wider environment (including plants and ecosystems) are closely linked and interdependent (FAO et al., 2019). Hence, OH is a wide-ranging concept that aims to integrate different disciplines, and analyses health at different levels: that of the individual, the population, and the ecosystem (Lerner & Berg, 2015). Following this approach, taking into consideration the interactions between animals-humans-ecosystems when assessing a health-related issue from a multidisciplinary perspective, will help improve health at the above-mentioned levels.

In the case of health literacy, if the OH approach (FAO et al., 2019) is considered, in addition to individual actions, social and political ones are also needed to protect the health of both ecosystems and animals, as well as public health. It can thus be said that critical health literacy (Nutbeam, 2000) becomes more relevant when taking an OH approach, and this should be addressed by education stakeholders.

Despite all governmental agency support (WHO, OIE, FAO, etc.), OH still needs to be incorporated into the educational system (Barret et al., 2010), and this requires that educational policies move towards this goal. However, educational institutions have not provided specific tools to promote this approach. An example of the shortages is that textbooks usually neglect zoonoses, as a Delphi study focused on contagious diseases that can lead to epidemics and pandemics pointed out (Kilstadius & Gericke, 2017). Informing students about zoonoses is coherent with the OH perspective, as understanding the emergence of zoonoses involves being able to identify the interdependent relationships between animal, ecological, and human health (FAO et al., 2019).

A recent publication has shown an increasing awareness among students towards health issues due to the COVID-19 pandemic outbreak (Rönner et al., 2023a). Despite the increasing inclusion of health issues in science learning, students have shown some limitations related to essential concepts of health education, such as the concept of 'infectious disease', the differences between virus and bacteria, or the relevance, efficacy, and functions of vaccines (Abramczyk et al., 2023; Calavia et al., 2022; Rönner et al., 2023a, 2023b).

The OH approach involves the development of ST to address complex health issues, since addressing them requires identifying the elements related to humans, animals and the environment, and analyzing how they interact and result in health-related phenomena such as pandemics.

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System Thinking (ST) for Addressing Complex Health Issues

The development of ST has been a focus in science education for a long time (i.e. Ben-Zvi-Assaraf & Orion, 2005; Hmelo-Silver & Pfeffer, 2004) and is achieving a growing presence in the science classroom (Ben-Zvi-Assaraf & Knippels, 2022). A recent work published by Momsen et al. (2022) proposes the use of ST to unify the learning of complex phenomena in Biology, synthesizing and extending the contributions of previous works (Ben-Zvi-Assaraf & Orion, 2005, 2010; Momsen et al., 2022; Sommer & Lücken, 2010). Research has shown the benefits of incorporating ST into science education compared to other teaching methodologies based on memorizing and reductionist approaches (i.e. Jacobson & Wilensky, 2006; York et al., 2019). As Hannon and Ruth (2000) stated, current science education still focuses on events rather than on processes over time, on parts rather than on systems and on isolated processes rather than on systemic relationships.

According to Ben-Zvi-Assaraf and Orion (2010), ST allows for the tackling of complex issues in a holistic way, identifying the factors involved, and the interdependent relationship between them. Ben-Zvi-Assaraf and Orion (2005) proposed that ST requires the development of a set of eight ST skills such as the following: identifying system components and processes; identifying the relationships between the components of the system; identifying the dynamic relationships within the system; developing Temporal thinking (retrospectively and prospectively).

From a Temporal thinking standpoint, a system is the result of several interactions that took place in the past, and the future of the system will be the result of the interactions that are being developed in the present. As Levrini et al. (2021) claimed, decisions and actions become directionless if they are not based on any image of the past, nor aimed at any stable future horizon. Complex health issues such as pandemics need to be addressed by connecting past and present events to make decisions based on these experiences to face potential future scenarios. Bielik et al. (2023) used concept maps elaborated by students to analyze their ST abilities on the COVID-19 pandemic, focusing on whether they referred only to biological aspects, or also to social aspects. They found that students reflected little in the dynamic sense (related to Temporal thinking).

Mehren et al.'s (2018) two-dimensional model highlights this Temporal thinking, as the dimensions proposed were: 1) Retrospective dimension (ST-OrgBeh) that includes issues related to the understanding of the system and its functioning (components and relationships), and that reflects knowledge of the system; 2) Prospective dimension (ST-Action) that refers to the ability to make forecasts and propose appropriate actions, which is related to the capacity to anticipate future events.

The topics used for the analysis of ST in Biology and Geology education were related to Earth, as an example of a complex, dynamic and changing system; this included topics such as the rock cycle (Ben-Zvi-Assaraf & Orion, 2005) and other geologic issues regarding climate change (Kali et al., 2003), ecosystem dynamics (Hmelo-Silver et al., 2017; Li & Li, 2023: Mambrey et al., 2022), the water cycle (Ben-Zvi-Assaraf & Orion, 2010) and the systemic nature of the human body (Tripto et al., 2013).

Tackling health-related issues from an ST and OH approach in science education is a nascent line of research (Puig & Uskola, 2021, Uskola & Puig, 2022, 2023). Uskola and Puig (2021) and Uskola and Puig (2022) performed diagnostic studies to explore pre-service teachers' ST and OH notion. The activities designed by Uskola and Puig (2023) for participants to develop ST were also conducted with pre-service teachers. Nevertheless, studies in secondary education, in which curricula ST and OH are gaining presence, are limited.

Research Aim and Questions

This work sought to make a contribution to this emergent field of research by exploring how secondary school students mobilize ST to address complex health issues, such as the COVID-19 pandemic, based on the OH approach. To achieve this aim, the following research questions (RQ) were proposed:

(RQ1) To what extent do secondary school students apply ST when identifying potential causes of the COVID-19 pandemic?

(RQ2) What are students' perceptions regarding the anticipation of future pandemics? And in what way are these perceptions linked to their ability to identify potential causes of future epidemics and to their recommendation of actions for preventing them?

(RQ3) How do students apply ST to define the OH notion after their engagement in activities that require its application?

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Research Methodology

General Background

The research consisted of a qualitative study that involved the collection and interpretation of data regarding the understanding of complex health issues, particularly the COVID-19 pandemic from a holistic view (Gibbs, 2012), as is the OH approach.

A case study, understood as an in-depth exploration from multiple perspectives of a particular case (Simons, 2011) was developed. Participants were all secondary school students (14-15 years old) in a state school classroom. They were engaged in a set of activities that were integrated into the current Biology curriculum with the objective of developing an understanding of the COVID-19 pandemic and developing ST skills in a complex health context using the OH approach, in March-April 2022.

Participants

The participants were from the same, single class of students (10 female, 8 male) chosen for convenience as the first author was one of the teachers at the time of implementing the activities. They were of a medium/medium-high socio-economic status and lived in urban or rural areas close to the city in which the educational centre was located. According to the Biology teacher, the group dynamics were good and showed interest in learning Biology topics.

All participants were properly informed by the researchers before starting the implementation. Their parents/legal guardians were provided with an informative document and the informed consent document was signed by the parents/legal guardians of each participant, according to the ethical law existing at the time of implementation.

Design and Implementation of a Teaching Sequence

A teaching sequence was designed by author 1 in collaboration with the other two co-authors and discussed with the Biology teacher. The sequence aimed to engage students in the construction of knowledge and the development of ST skills using the OH approach in the context of the COVID-19 pandemic. Furthermore, the activities aimed to make students aware of the role of human beings in the emergence of infectious diseases, and in the actions we can take to minimize the risk of the emergence of new diseases (agency).

The sequence was integrated in Biology teaching as part of the complex health issues learning. It should be considered that this is the first time that the participants learned about health topics from an OH approach. Table 1 shows the activities, their distribution in lessons, the learning goals, and their use for addressing the RQs.

Table 1
Activities of the Teaching Sequence

Lesson	Activity/ Task	Individual (I)/ Group(G)	Learning goals	RQ addressed
1	T1.1	G	To express key aspects that define the notion of health	-
	T1.2	G	To identify diverse infectious agents and to explain how to treat them	-
2	T2.1	G	To explain infectious diseases	-
	T2.2	I	To explain the main factors that influence the occurrence of the COVID-19 pandemic and the relationships between them	RQ1, RQ3
3	T3.1	I	To apply ST to identify the main causal factors of the COVID-19 pandemic and the potential emergence of future pandemics	RQ1, RQ2, RQ3
	T3.2	G	To identify other examples of diseases that could potentially become pandemics	-
4	T4.1	G	To reflect on the consequences of human activities on public health	-
	T4.2	G	To critically analyze the information provided in diverse case studies related to zoonotic diseases	-
5	T5	I	To define OH	RQ3

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Students worked individually and in small groups (3-5 students). In the beginning, the first three tasks, T1.1, T1.2 and T2.1, were carried out in these groups (Figure 1) to facilitate the sharing of their ideas. T2.2 ("Draw up a scheme or diagram in which you indicate the factors that you think influenced the COVID-19 pandemic. They should also indicate the relationship between the factors, if known") required the individual production of a diagram or drawing.

Figure 1
Group of Students Working in T2.2

T3.1 consisted of an individual questionnaire designed by the authors based on previous works on ST (Uskola & Puig, 2022, 2023). It was designed to encourage students to think about the potential causal factors of the origin of the COVID-19 pandemic and explain the likelihood of the emergence of new pandemics in the future. Table 2 shows the questions and the aspects analyzed linked to the RQs.

Table 2
Questions in T3.1 Analysed for Addressing the RQs

Questions	RQ addressed	Dimensions
T3.1.4 What individual actions do you think can help prevent new pandemics, such as COVID-19?	RQ2	Actions
T3.1.5 Do you think this COVID-19 pandemic was a one-off event or do you think more pandemics may occur in the future? Give your reasons.	RQ1 RQ2	ST (Temporal thinking) Anticipation
T3.1.6 What do you think are the cause(s) of the current COVID-19 pandemic?	RQ1 RQ3	ST (Components, Relationships, Causes)
T3.1.11 Do you think humans can anticipate the emergence of new pandemics?	RQ2	Anticipation

T4.1 was designed to help students establish relationships between human actions and the emergence of infectious diseases. T4.2 consisted of the analysis of diverse hypothetical cases of zoonosis designed by author 1, inspired by the resource developed by Michigan State University (2023).

Data Collection and Analysis

Data included the written reports produced by the students during the development of all activities. Additionally, joint discussions during the activities were audio-recorded, as Figure 1 shows, and field notes were taken.

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For RQ1, diverse sources of data were used: the diagrams elaborated by students individually in T2.2, as well as individually written responses to T3.1. The content of the diverse sources of data was analyzed in order to examine the ST shown by students. To do such an analysis, the characteristics of ST defined by Ben-Zvi-Assaraf and Orion (2005) and Mehren et al. (2018) were taken into account. Thus, four dimensions of ST were considered, and the levels were established in interaction with data for each ST aspect which are shown in Table 3:

1) Components: this refers to the elements of the system (Li & Li, 2023). In this study, these components concern the three spheres (human, environmental, and animal health) of the OH notion (FAO et al., 2019).
2) Interactions: this corresponds to the identification of the relationships or connections between the components of the system (Ben-Zvi Assaraf & Orion, 2005), in this case, among the elements of the three OH spheres.
3) Causal relationships: this refers to the cause-effect relationships (Mehren et al., 2018) that students established among the elements of the three OH spheres. As the Interactions aspect includes co-occurrence but does not necessarily involve causality, we also studied the identification of causal relationships as an essential dimension of ST. The distinction between interactions and cause-effect relationships has been made in previous works such as the one cited by Mehren et al. (2018) and more recently by Bielik et al. (2023) in the context of applying ST to the conceptualization of COVID-19. A distinction was made between these two levels: 'simple structural relationships' and 'simple mechanistic relationships'.
4) Temporal thinking: as mentioned above, this refers to the ability to connect past and present experiences/events to the future (Ben-Zvi-Assaraf & Orion, 2005; Mehren et al., 2018).

Table 3
Dimensions and Levels for ST Analysis

ST dimensions	Levels
Components	Level 3. Three spheres (H-E-A)
	Level 2. Two spheres
	Level 1. One sphere (A, H or E)
	Level 0. No sphere
Interactions	Level 1. Identifying interactions among elements
	Level 0. Not identifying interactions among elements
Causal relationships	Level 1. Establishing cause-effect relationships
	Level 0. Not establishing cause-effect relationships
Temporal thinking	Level 2. Connecting with past and present
	Level 1. Connecting with past/present
	Level 0. Not connecting with past/present

Concerning RQ2, the analysis involved three steps and the levels were established taking the data into account. First, students' perceptions about Anticipation (Table 4) were explored. Anticipation can be defined as the ability to predict future challenges based on past events, current evidence and knowledge (Deans, 2021). This is a fundamental skill of ST, and essential for fostering decision-making. The responses to question T3.1.11 (Table 2) were assigned to a particular level (Table 4). Level 0 was assigned to those students who said it was impossible to anticipate future pandemics. Level 2 was assigned to those who said it was possible, and vague responses were assigned to Level 1.

Secondly, the actions proposed by students to question T3.1.4 concerning how to prevent future pandemics were examined. The responses were classified as mitigation actions (Level 1), need for information (Level 2) and actions directed to causes (Level 3) (Table 4). Finally, this research explored whether the students identified the potential causes of future pandemics when making predictions in question T3.1.5, considering that the ability to identify potential causes of a specific problem also shows a high degree of ST development.

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Table 4
Dimensions and Levels for Analysing Students' Perceptions on Pandemics

Dimensions of students' perceptions	Levels
Anticipation	Level 2. It is possible to anticipate future pandemics, and the answers are justified
	Level 1. It is possible to anticipate future pandemics, but vague and not justified answers were provided
	Level 0. It is impossible to anticipate future pandemics
Actions	Level 3. Actions directed to causes
	Level 2. Need for information
	Level 1. Mitigation actions
	Level 0. No actions proposed

Concerning RQ3, the analysis applied the dimensions and levels shown in Table 3. These levels were used to examine the responses to T5 (OH context) and to compare them with the COVID-19 context (highest level in T2.2 and T3.1). This analysis was performed to identify the evolution of the students' conception of OH and, hence, the evolution of ST-related skills.

Research Results

Application of ST in the Identification of COVID-19 Pandemic Causes

Table 5 shows the frequency of students' (S) responses in each level regarding ST in each of the questions analyzed.

Table 5
Frequency of Students in Each ST Dimension and Level

ST dimension	Level	Activity/Task			
		T2.2	T3.1.6	T2.2/T3.1.6	T3.1.5
Components	3	0	0	0	-
	2	10	7	15	-
	1	8	11	3	-
	0	0	0	0	-
Interactions	1	5	6	10	-
	0	13	12	8	-
Causal relationships	1	5	7	10	-
	0	13	11	8	-
Temporal thinking	2	-	-	-	2
	1	-	-	-	12
	0	-	-	-	4

Note. T2.2/ T3.1.6 column shows the highest level reached.

As is shown in Table 5, most students mentioned two of the three OH spheres when explaining the COVID-19 pandemic (Components, Level 2). The animal sphere was the most cited after the Human sphere, while only one student referred to the Environment. None referred to all three spheres (Components, Level 3). Only three students mentioned two spheres in both questions. In the following example, S2 referred to Animal and Human spheres (Interactions, Level 1).

S2 (T3.1.6): 'I think a virus that used to be in animals mutated and made people infected.'

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More than half of the students identified Interactions between the components at least in one of the questions, but most students did so only when responding to one of the two questions, and only one student did so in both responses. The response of S2 given above shows a relationship between the spheres but the following example of S10 does not (Interactions, Level 0), although S10 did refer to Animal and Human spheres:

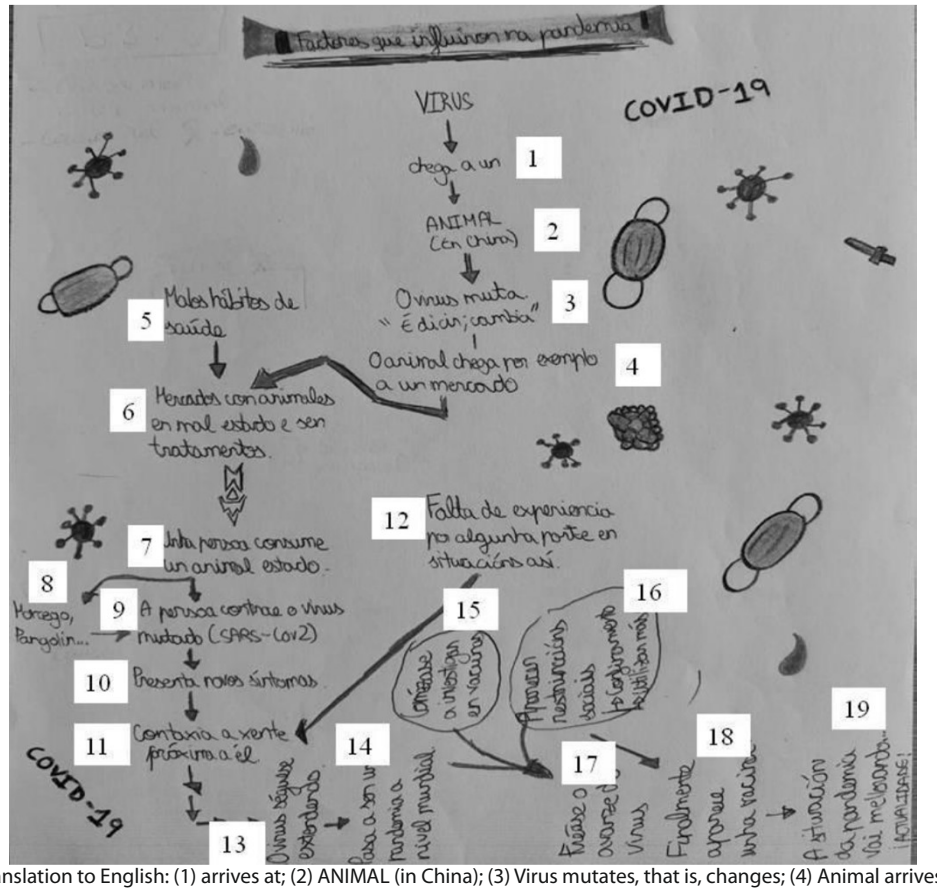
> *S10 (T3.1.6): 'A mutation of a virus that affected animals. Then, a massive contagion due to misinformation in the early days.'*

Similarly to the findings in Interactions, more than half of the students identified Causal relationships at least in one of the questions (Causal Relationships, Level 1), but the majority of students did so only when responding to one of the two questions, and only one student did so in both responses. The response of S2 given above shows that S2 identified the origin of a zoonotic disease (Causal Relationships, Level 1). Besides a zoonotic origin, an accidental or deliberate origin in a laboratory was the other type of cause identified, as the example of S16 shows:

> S16 (T3.1.6): 'I believe it was a virus created to decrease the world's elderly population in an attempt to avoid a major economic crisis, which would explain the rapid creation of the vaccine and the absence of cases in the initial country (China).'

Figure 2 shows the diagram elaborated by S17 in response to T2.2.

Figure 2
Diagram made by S17 in T2.2



Note. Translation to English: (1) arrives at; (2) ANIMAL (in China); (3) Virus mutates, that is, changes; (4) Animal arrives for example at a market; (5) Bad health habits; (6) markets with animals in poor condition; (7) one person eats an animal in poor condition; (8) Bat, pangolin; (9) a person contracts the mutated virus (SARS-CoV2); (10) presents new symptoms; (11) spreads to people close to him; (12) Lack of similar experiences; (13) The virus continues to spread; (14) Becomes a global pandemic; (15) Vaccine research begins; (16) They propose social restrictions (confinement and use of masks); (17) the advance of the virus is slowed down; (18) a vaccine finally appears; (19) the pandemic situation is improving PRESENT.

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It can be observed in Figure 2 that S17 drew a diagram in which he progressively explained the potential causes of the pandemic by connecting (using a sequence of arrows) diverse events that are part of human and animal spheres. S17 referred to the causal relationship (Causal Relationships, Level 1) between animal and human health (*'one person eats an animal in poor condition', 'one person contracts the mutated virus SARS-CoV2'*, '(the person) *spreads it to people close to him*').

Regarding Temporal thinking, it is important to highlight that all students predicted that pandemics will occur in the future, and the majority (12/18) referenced either past (7/18) or present (5/18) events to elaborate and justify their answer, as the following examples show:

> S4 (past): *'I think that this was not a one-off event and that more may occur in the future. I think this because there have been others in the past and there is no way of knowing whether there will be more in the future, although it is most likely.'*

> S7 (present): *'I believe that more pandemics may occur in the future as new diseases and new viruses appear every week.'*

S4 based the response on past events, whereas S7´s prediction was based on the present. Both were coded in Temporal Thinking Level 1.

Students' Perceptions About Anticipating Future Pandemics

Table 6 shows the results of the analysis of students' perception concerning the possibility of anticipating future pandemics, with the frequencies of each level and examples that illustrate them.

Table 6
Frequency of Students´ Anticipation Responses

Level	Frequency	Example
2 Possible to anticipate	4	S17: *'Yes, I think that even if humans do not know exactly when and where a new pandemic will start, what they can do is to prevent them, by increasing safety with more hygiene and so on'.*
1 Not clear	5	S10: *'I´m not sure but it's possible that somehow they can be foreseen, although not with much certainty, although I'm not sure'.*
0 Impossible to anticipate	8	S2: *'I think there is nothing we can do about it because anything can cause it'.*
Not answer	1	-

The perception of most students (8/18) was that it is not possible to anticipate future pandemics (Level 0), whereas the minority (4/18) considered it possible to anticipate them (Level 2). In the category of 'Not clear' (Level 1), five responses were included. All of them showed doubts about the possibility of anticipating future pandemics, although they did not develop their responses by providing justification for their answers.

Only 7/18 students were able to identify the potential causes of future pandemics. These included: mutations (3/18), emergence of new viruses and diseases (2/18), lack of health measures (1/18), and the way we act in the world (1/18). Regarding the actions to prevent future pandemics, most students (13/18) proposed immediate actions such as the ones applied to prevent the spread of COVID-19: sanitary and safety measures, for example, using masks and keeping your distance. Four students pointed to the need to be 'well' informed to act responsibly against future pandemics.

No student proposed actions to attack the causes of pandemics. The rest of the students (4/18) did not propose any actions; indeed, three of them argued that future pandemics cannot be avoided since they are natural events. The analysis of the potential relationship between students' perception of the possibility to anticipate future pandemics and the identification of causes and actions is displayed in Figure 3 (individual responses).

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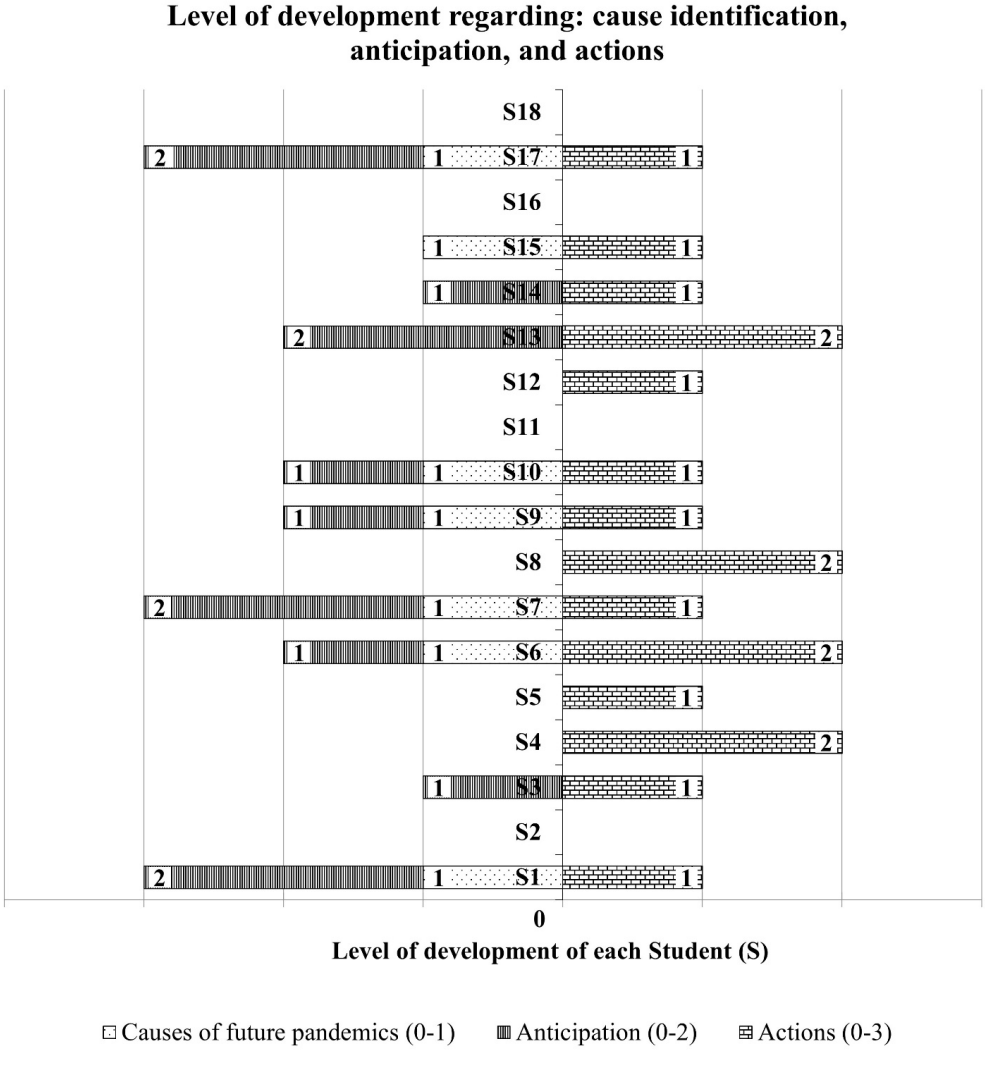
Figure 3
Students' Perceptions about the Capacity to Predict Future Pandemics and Students' Identification of Causes of Pandemics and Actions to Prevent Them.



As can be seen in Figure 3, all the students who identified causes for future pandemics perceived that it was not impossible to anticipate them. Only one student (S15) did not respond. Additionally, the four students who did not propose any action considered that we cannot anticipate future pandemics, nor did they identify potential causes of future pandemics.

Students' OH Notion

Figure 4 shows the responses of 14 students to question T5. Four students did not answer.

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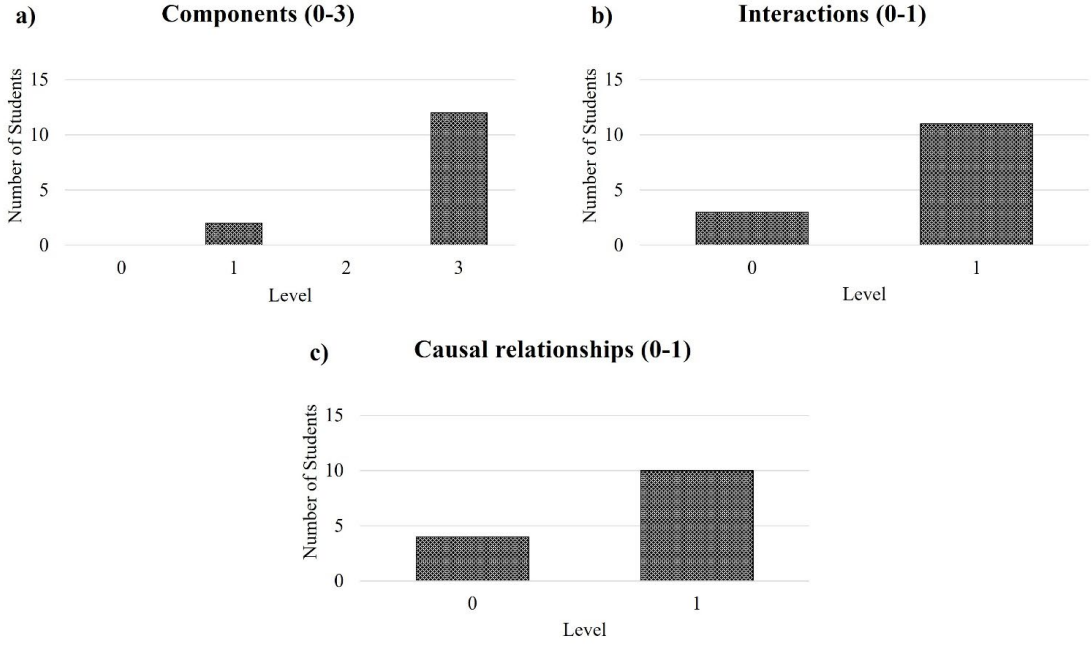
Figure 4
Frequency of Students´ Responses in each Level of ST Dimensions in the OH Context



Note. a) Components, b) Interactions, c) Causal relationships.

Figure 4a shows that 12/14 students mentioned the three spheres of the OH notion, as well as reaching the highest level for this aspect (Level 3), which no students did in the COVID-19 context initially (Table 5). The majority of students identified interactions between the spheres (Figure 4b) and reached Level 1. This dimension also showed better performance in the final context than in the initial one, as the comparison between Table 5 and Figure 4b shows. Indeed, they used words such as dependence (6), interrelationship (5), affect (3) and interconnection (1).

Moreover, 10/14 gave examples where they established causal relationships for the occurrence of pandemics reaching Level 1 (Figure 4c). Similarly, in the case of causal relationships, the results were better in the final context than in the initial one, as the comparison between Table 5 and Figure 4c shows. The following example of S14 illustrates this:

> S14: *'The concept of OH advocates that the health of animals, people, and ecosystems/environment are interrelated, so what happens in one will affect the others.*
> *For example, if we destroy the health of ecosystems and the environment and deforest a place, the animals that used to live there can go to other places and infect people with their diseases. Destroying the health of the environment would have an effect on the health of animals and humans.'*

Figure 5 shows the level reached by each student in both contexts, the initial COVID-19 context, and the final OH context, with reference to ST dimensions.

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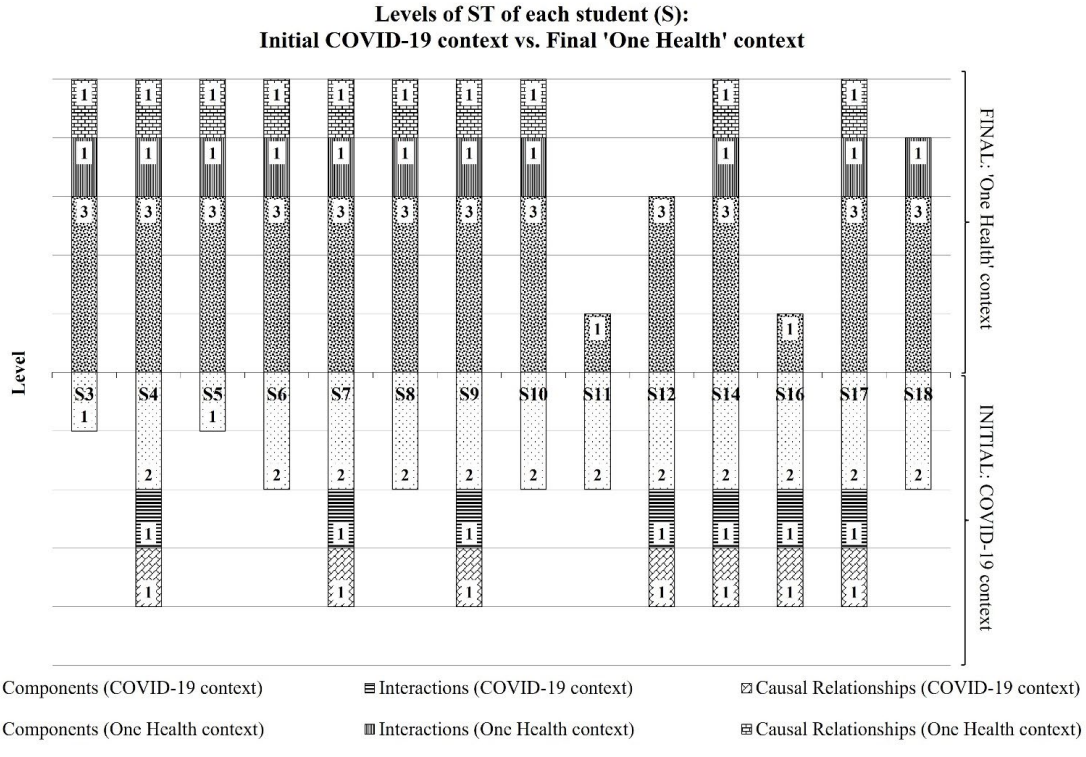
Figure 5

Comparison of the Degree of Students' ST Development between the Initial Context (COVID-19 Context) and the Final Context (One Health Context).



As can be seen in Figure 5, two students, S11 and S16, did not develop a notion of OH: S11 thought that it referred to only presenting one kind of human health, for instance, physical or mental, but not both, and S16 referred to health being delicate and easy to lose. Regarding the rest of the students, S12 was the only one that was able to identify the three spheres but was not able to interrelate them. Comparing the OH context with the initial COVID-19 context, some noteworthy answers can be seen in Figure 5, such as those of S3 and S5 that only referred to human aspects initially and showed a complete OH understanding at the end of the sequence.

Discussion

This study aimed to explore how a group of secondary school students mobilized ST in order to address complex health issues such as the COVID-19 pandemic using the OH approach. Regarding RQ1, students identified two of the three components of the OH notion, mainly animal and human health. Furthermore, more than half identified interactions between the components, and showed simple causal thinking. For example, they attributed the pandemic to a single cause, either a zoonosis or its creation in a laboratory. Nevertheless, the results are better than those in a previous study (Puig & Uskola, 2021), in which pre-service teachers focused on factors related to the health measures implemented after the onset of the COVID-19 pandemic, mainly focusing on human health. In this case, participants showed awareness of zoonosis, which is fundamental for developing contagion and health literacy (Kilstadius & Gericke, 2017). At the time this study was implemented, the notion of zoonosis was more mediatic than the time of the previous one (Puig & Uskola, 2021). This may affect the results since students could be more familiar with zoonosis.

The analysis of ST related to other areas of Biology and Geology, such as the human body (Snapir et al., 2017), ecology (Mambrey et al., 2020; Riess & Mischo, 2010) or geology (Ben-Zvi-Assaraf & Orion, 2005), has generally shown a higher degree of ST than that observed in this work: one example, regarding the most basic feature of ST, is the identification of system components. This may be explained by the complexity of considering so many factors (environmental, human and animal) that were present in the COVID-19 pandemic.

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Students pointed to two alternative explanations regarding the potential causes of the COVID-19 pandemic: 'the virus was created or escaped from a laboratory' and 'the zoonotic origin of the infectious disease', which correspond to human and animal spheres, respectively. This is coherent with the information disseminated by the media and reflects students' questioning on this issue, considering it to be an unsolved problem. ST aims to help students to understand and to explain the systemic nature of natural phenomena. However, this study showed that when controversy affects even the identification of system components, other ST dimensions (e.g., connecting elements of a system) are difficult to activate. These results also showed the need to specifically promote ST-related skills for health literacy in Biology education.

Addressing RQ2, only four students believed that it was possible to anticipate future pandemics, although all 18 students responded that they thought that future pandemics would indeed occur. Anticipating future pandemics is crucial for preventing them, and the ability to anticipate is part of future thinking (FT) skills (Levrini et al., 2021). Anticipating the future, imagining the future, was the dimension that the students participating in Levrini et al.'s (2021) study were least able to develop. According to these authors, FT *'refers to mid-long term thinking and the 'imagination dimension' which are particularly difficult to develop in a short time'* (p. 297).

As the results reflect, this ability to anticipate is linked to the identification of causes, as all the students who identified potential causes of future pandemics believed that it was possible to anticipate them. Despite the limitation of the sample in this study, the relationship between the ability to anticipate future events and the ability to propose actions (agency), is shown by the results: the four students who did not propose any action considered that we cannot anticipate future pandemics and did not identify causes of future pandemics either.

Moreover, the results show that in the cases in which students identified causes of future pandemics, a few referred to virus mutations, but did not consider the causes that they had pointed out in the case of COVID-19. For instance, no student referred to animal health problems as being possible causes of pandemics. This issue can also help to explain the type of actions that the students suggested for preventing pandemics; that is to say, no student proposed actions aimed at addressing the causes of pandemics (e.g. zoonoses). Indeed, they mostly limited themselves to proposing hygiene measures or the need for information. Students used their own experiences to propose direct actions such as the ones they carried out to prevent the spread of COVID-19 (e.g., washing their hands, using face masks, keeping their social distance, etc). This is also coherent with previous research (Uskola & Puig , 2022), and reflects that personal experiences play a predominant role, in contrast to indirect actions that involve policy measurements: students revealed some "functional" health literacy but a lack of "critical" health literacy (Nutbeam, 2000). This research therefore highlights the need to provide a wider, more complex view of health problems in order to foster student agency.

RQ3 showed that the definitions of OH presented by the participants reflect an awareness of the relationships between the three spheres of this notion. They also highlight students' capacity at the end of the activity sequence to apply this notion to other health-related examples, such as zoonoses and the occurrence of pandemics. This positioned them as expert learners in ST (Hmelo-Silver & Pfeffer, 2004).

Initially, they were not able to transfer what they knew about the origin of the COVID-19 pandemic to future pandemics. This is shown by the fact that they related to some extent the causes of the COVID-19 pandemic to our relationship with animals (to a lesser extent with the environment). However, when it came to justifying the possible appearance of future pandemics, they referred to mutations, the appearance of new viruses, but hardly at all to the relationship of humans with animals and ecosystems, or to the consequences of human actions. This made it difficult for them to anticipate future pandemics and to propose actions to prevent them. None of the actions proposed revealed the application of the OH approach.

In contrast, at the end of the sequence, participants showed an adequate understanding of the OH notion. They referred to the relationship between human, animal and environmental health, and also provided examples of how zoonoses emerge and of the influence of human actions on their emergence.

Another noteworthy issue is that most students proposed immediate mitigation actions to prevent pandemics, as explained previously. This points to the need to promote FT as a way to encourage students to move in the timespan to propose actions that integrate not only personal experiences, but also information of past episodes; this requires prospective thinking (Levrini et al., 2021; Mehren et al., 2018). Anticipating the future is an advantage, since it helps to take actions that can influence the evolution of facts (e.g. preventing the emergence and spread of zoonosis) and assists in the definition of the most potential favorable scenarios.

It should be considered that the holistic approach of the learning activities implemented in this study differed from the one these students were frequently involved, in which OH was not connected to health topics, and this might influence the results obtained. Besides, the selection of participants was done for convenience. Further

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research developed in other groups and countries will be helpful to enlarge the body of knowledge in this line of research.

Conclusions and Implications

This research intended to explore how upper secondary school students mobilized ST to tackle COVID-19 based activities. The interpretative analysis of students' written productions showed that students articulated several ST aspects, although not consistently. Most students improved their OH notion after completing the activities, being able to identify components, relationships, and provide examples of causal relationships. As the results of this study suggested, using an OH approach can be a suitable way to engage students in fostering and applying ST skills, although further studies are required to provide more evidence to support this. The activity sequence could be revised and introduce modelling strategies, as representations facilitate students to address the cognitive demand of reasoning with systems.

Promoting the OH notion and ST-related skills can improve students' health literacy, enabling them to take informed actions. The sequence presented in this work may allow students to better understand health as a global issue even when OH is not explicitly mentioned. For instance, it can enable students to learn how environmental changes, such as habitat fragmentation due to urbanization or biodiversity loss, increase the frequency of contacts between animals and humans, thus increasing the likelihood of transmission of infectious diseases between them. This approach would give special emphasis to the importance of taking action to maintain the health of animals, humans, and ecosystems.

Declaration of Interest

The authors declare no conflict of interest.

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Inés Martinez Pena
(Corresponding author)
PhD, RODA research group, Area of Didactics in Experimental Sciences, Department of Applied Didactics. Faculty of Education Sciences (north campus), University of Santiago de Compostela (USC), Spain.
E-mail: inesmartinez.pena@usc.es
ORCID: https://orcid.org/0000-0001-5595-3405

Blanca Puig
RODA research group, Area of Didactics in Experimental Sciences, Department of Applied Didactics. Faculty of Education Sciences (north campus), University of Santiago de Compostela (USC), Spain.
E-mail: blanca.puig@usc.es
ORCID: https://orcid.org/0000-0002-2503-7032

Araitz Uskola
PhD Science (Chemistry), Senior Lecturer, Area of Didactics of Experimental Sciences, Department of Didactics of Mathematics, Experimental and Social Sciences, Faculty of Education, University of País Vasco/Euskal Herriko Unibertsitatea (UPV/EHU).
E-mail: araitz.uskola@ehu.eus
ORCID: https://orcid.org/0000-0003-0621-3085

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