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Developing systems thinking to address Climate Change

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Abstract

Purpose - The objective of this research was to evaluate the presence of systems thinking after an educational proposal on climate sustainability based on reflection and video creation. To evaluate this competency, an evaluation rubric was constructed.

Design/methodology/approach - The research is a case study with a mixed approach. It was carried out with 82 future teachers of Primary Education, making content analysis of the videos made. For the design of the rubric, a specific review of the literature was conducted.

Findings - The results showed that trainee teachers can identify, relate, and understand interconnected processes, but have difficulties in thinking temporally or in understanding the hidden dimensions of the system. The results reveal how the development of systems thinking in the Climate Change framework is a complex learning process. The rubric created allowed us to systematize the evaluation by making it possible to assess the subskills involved.

Originality/value - To improve the development of systemic thinking, using real data linked to the consequences of this problem and ICT applications that foster an approximation to future realities is suggested. In addition, conscious and fair decision making should be promoted on the basis of a transformative education that favours this thinking in interaction with other key competences in sustainability. The innovative rubric allows the evaluation of systemic thinking skills for the study of climate change, conceptualized from the interrelationships of the natural, social, and economic dimensions and from its implications for life, on different geographical and temporal levels.

Keywords Teacher Training, Systems thinking, Education for sustainable development, Climate Change, Key competences for sustainability.

Paper type: research paper

1. Introduction

The Earth System's current state is determined by severe global environmental change. Recent research into planetary boundaries has shown how this global change disrupts the stability of interconnected Earth processes, such as climate change, ocean acidification, and biodiversity loss, placing humanity in a situation of chaos and uncertainty (Rockström et al., 2023).Climate change is already considered a paradigmatic example of this process, due to its anthropogenic origin and its impact on all components of the Earth system (physical, chemical and biological) (Steffen et al., 2015).

The main concern is that the problem shows no signs of slowing down. The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2022) indicates that the continuing exponential increase in greenhouse gases is causing serious disasters, affecting the health and well-being of both people and natural ecosystems. Disadvantaged and vulnerable populations are most at risk from this problem, depending on their geographical exposure and their ability to adapt and their resilience (IPCC, 2022).

The underlying reason for this socio-environmental crisis is that our development model persists in erroneously linking the idea of progress to economic growth, consumerism and the chimera of technological control (Bauman, 2013; Morin and Petit, 2011). Thus, it is well known that many of the causes of the current climate emergency are associated with a dominant, neoliberal, capitalist economic system (Chomsky and Pollin, 2020).

2. Literature background

2.1 Climate education in higher education

The climate emergency requires radical measures to help mitigate and adapt to climate change (IPCC, 2022), which will require an educated and informed citizenry, capable of thinking critically, making decisions and introducing changes in their lifestyles. Within this framework, the 2030 Agenda’s (UN, 2015) SDG 4, on quality education, states that this is a key element for achieving real sustainable development.

This situation demands that universities promote transformative education that contributes to strengthening the professional competences needed to face the social, economic and environmental challenges (Leal Filho and Pace, 2016; Brundiers et al., 2021). There is a need for action-oriented transformative pedagogy that engages learners in participatory, systemic and innovative thinking and action processes in the context of local communities and learners' everyday lives (UNESCO, 2017). From this framework, empowering citizenship and developing sustainable competences require pedagogical approaches that focus on learning processes, rather than the accumulation of knowledge, to educate people with participatory, adaptive and resilient capacities, through skills such as teamwork, critical and systems thinking and problem solving (UNESCO, 2017). Thus, by integrating education for sustainability into teacher training, the aim is for teachers to learn to be, think and act differently in order to address the complexity of today's problems.

Schools and higher education must therefore take urgent steps to include training in climate sustainability education in their curricula, contributing to the development of key competences for sustainability and promoting sustainable decision making at personal and professional levels. This would involve rethinking how to address a global, complex and anthropogenic problem. These new ways must be linked to the achievement of quality education, capable of transferring to the classroom the need to reverse the exponential increase in current socio-economic and environmental trends (Steffen et al., 2015). From this perspective, the search for real sustainability must be approached from a systemic perspective that prepares citizens for constant change, uncertainty and lack of knowledge, as part of the interdependent relationship that exists between humans and the biosphere (Mikulčić et al., 2022).

Therefore, climate education should start from research into this problem, promoting the study of the causes, consequences and possibilities for action (Varela-Losada et al., 2019), in such a way that its approach favours the connection of the global situation with the local consequences close to the students (Monroe et al., 2019), and studying the scientific, social, ethical and political dimensions from a complex perspective (Rousell and Cutter-Mackenzie-Knowles, 2020). Educators must not only address complex science, but also consider sociocultural factors, such as the values behind possible solutions or the media's treatment of the problem (Monroe et al., 2019).

This brings us to the need to integrate competences that promote sustainable development in higher education (Wiek et al., 2011; Leal Filho et al., 2021). As discussed by some authors (Wiek et al., 2011), this challenge also entails certain difficulties since, to begin with, it is necessary to clarify what these competences in sustainability are. Thus, there are different proposals to be considered (Wiek et al., 2011; UNESCO, 2017; Brundiers, 2021). Furthermore, it is necessary to bear in mind that this framework should not be presented as a list of elements but as a set of interrelated and interdependent competences, required in combination to solve sustainability problems (Brundiers et al. 2021). This said, some studies also point to a certain prevalence of some of these competences, highlighting systems thinking as a basic starting element for understanding the nature of socio-environmental problems (Demssie et al., 2019). Citizens must be able to deal with the transformations required for sustainable development, which are often complex problems involving ethical issues. Decision making, therefore, requires an understanding of the complexity of these problems so that they can be mobilised in an interrelated way with other competences, such as critical thinking, normative competence, interpersonal competence or anticipatory competence.

2.2 Systems thinking for climate education

A system can be defined as a "set of interacting elements", whose existence and functions are maintained as a whole by the interaction of its parts (Bertalanffy, 1968, 1993). These elements, in a complex system, form a multi-level structure and can evolve over time. Systems are also characterized by interconnected and dependent parts that function as a whole and their behavior depends on the overall structure. They are usually open and made up of hierarchical subsystems and their components interact in a non-linear way, which makes it difficult to establish cause-effect links between their dynamic relationships (Ben-Zvi Assaraf and Orion', 2005; Roychoudhury et al., 2017). From this perspective, systems thinking is the ability to identify not only the components and structures of which it is comprised but to explain, describe and quantify the dynamics that occur in a natural and complex system, such as climate (Roychoudhury et al., 2017).

As a complex natural system, climate is an example of how, in a system, materials and energy are transferred inside and outside it, as well as among its components, and of how a change in one variable can alter the stability of the system, leading to alterations in the interrelated processes. The process of climate change is, therefore, a multidimensional and systemic process (Weber, 2010) and dealing with it requires specific skills that enable phenomena to be seen as interconnected and dynamic, whose parts act in interacting networks (Dyehouse et al., 2009).

In the framework of key competences for sustainability, Wiek et al. (2011) point out the importance of systems thinking to collectively analyze complex systems in different domains (society, environment, economy, etc.) and on different scales (from local to global). Crofton (2000) considers that this competence can facilitate the understanding of the systemic nature of the world and the ways in which the natural and human systems are interconnected. He argues that it can also help identify and account for the direct and indirect consequences for people and ecosystems based on an understanding of the global nature of the world and how local and regional issues are part of the whole.

In literature, we find many studies that address systems thinking in the context of natural systems from an educational perspective. Three interesting literature reviews have been conducted in recent years in relation to systems thinking training. Yoon et al. (2017) conducted a review of empirical studies (1995-2015) in K-12 science education. And in the framework of STEM education, York et al. (2019) from 1985 to 2019, and Bielik et al. (2023), from 2000 to 2020, characterised the literature on the teaching and learning of systems thinking. All three studies show an emerging trend in research on this competence. The areas that dominate the subject are biology, ecology and environmental sciences (Yoon et al., 2017; York et al., 2019; Bielik et al., 2023). Thus, in the reference literature we can find examples of the development of this competence in relation to different processes and systems, such as the functioning of ecosystems (Mambrey et al., 2020), the water cycle (Ben-Zvi Assaraf and Orion, 2005), human-environment systems (Mehren et al., 2018) or sustainability (Voulvoulis et al., 2022). In relation to the elements that form systems thinking, the studies reviewed by Yoon et al. (2017) and York et al. (2019) paid more attention to the structures of systems and processes, focusing especially on helping to recognise relationships/interdependencies, in such a way that interventions that examine the states of systems are lacking. These three review articles, therefore, highlight the need for further research and design proposals on the modelling of these processes, which also address, for example, improving the conceptualisation of emergent schemes (such as the spillover effects of change) and the ability to make predictions.

Teachers are a key element of the educational process. However, Bielik et al. (2023) point out that most of the studies on systems thinking are focused on higher education students and, like Yoon et al. (2017) and York et al. (2019), they detect a lack of research on trainee and in-service teachers. Research also shows that teachers have significant deficits in relation to complex processes (Yoon et al., 2017). Among this literature we also find few examples that focus on designing and evaluating training actions that address systems thinking within the framework of climate systems. These include the approaches by Roychoudhury et al. (2017) and Jacobson et al. (2017).

There is also research that designs assessment instruments for this competence for different educational levels (Ben-Zvi Assaraf and Orion, 2005; Hung, 2008; Arnold and Wade., 2017; Mehren et al., 2018; York, 2019; Lavi and Dori, 2019; Feriver et al., 2019). But when analysing these studies (see Table 1), we again find that they tend to focus on natural issues only, without meaningfully integrating the influence and consequences of human activities on the system.

Table 1.
Characteristics/dimensions of the different rubrics and conceptualisations of systems thinking

Author	Ben-Zvi Assaraf (2010)	Hung (2008)	Arnold (2017)	Mehren (2017)	Catalina Foothills School (2018)	Feriver (2019)	Lavi (2019)
Context	*Junior high school students Israel*	*Master students USA*	- *USA*	*Secondarystudents Germany*	*Grades K-2 USA*	*Preschool student with university parents Germany and Turkey*	*Science and engineering teachers Israel*
Components and Structure	Identify the components and processes within the system Identify relationships among the system's components Organize the systems' components and processes within a framework of relationships	Identification of crucial variables Linearity Interconnectivity	Content (What's in the system) Structure (How's it organized)	System organisation (structure, limits)			Structure (main object and its subobjects structural links)
Behaviour	Make generalizations Identify dynamic relationships within the system Understand the hidden dimensions of the system Understand the cyclic nature of systems Think temporally	Cause-effect relations (causal-loop) Feedback processes (positive and negative) Dynamics processes Contextualization Underlying mechanism (explanatory knowledge)	Behavior (What happens when content and structure interact)	System behaviour (emergence, interaction, dynamics)	Change over time Interdependencies Consequences System as Cause Leverage Actions Big Picture	Hidden dimension Seeing the whole Recognition of causality Understanding systems mechanisms Identifying and understanding feedback Future prediction Understanding dynamic behavior Identifying intervention points	Behaviour (procedural links, complexity levels, procedural sequence)
Others			Mindset (How to approach systemic problems)	System-adequate intention to act (prognosis) System adequate action (regulation)	Self-Regulation and Reflection		Function (expected outcome / intendedpurpose; main function)

Therefore, within this framework, the aim of this research was to evaluate the presence of systems thinking in a training action on education for climate sustainability with teachers in initial training, paying special attention to the interaction of the natural and social spheres. For this purpose, a rubric was constructed to assess the mastery of this competence.

3. Training program

Education for climate sustainability (SDG 4 and SDG 13) is the core of the training activity carried out. The aim was to address, from the perspective of university teacher training, experiences linked to the development of systems thinking.

With the purpose of providing benchmark training activities, one linked to the socio-constructivist paradigm and Activity Theory (Daniels and Hedegaard, 2011) was implemented, bearing in mind that in order to promote systems thinking it is necessary to design interdisciplinary experiences (Alm et al., 2021), which facilitate the construction of shared thinking and contribute to the introduction of new ways of thinking about complex problems (Montana-Hoyos and Lemaitre, 2011).

By taking the Activity Theory as a reference, the aim was to guide complex educational actions, giving the participants prior information on the objectives sought, the actions to be carried out and the appropriation, by the students, of the assessment instruments (Talizina, 1988). In this way, the aim is to promote self-regulation of learning, so that future teachers can become aware of the learning process, fundamental elements for promoting complex and interrelated competences such as systemic thinking. As Bjork et al. (2013) point out, the complexity and speed at which changes occur in the earth system necessarily require teachers and students to be able to manage their own learning activities.

Furthermore, as the literature points out, there is a need to learn about systems thinking *while* applying systems thinking to a concrete context (York et al. 2019), in this case through the study of climate change within the framework of global environmental change.

From this approach, as can be seen in Table 2, the didactic sequence was structured in different phases associated with the development of systemic thinking skills (Lorenzo-Rial et al., 2023). As a guide, within the framework of transformative and self-regulated learning, guiding questions were formulated to orient the learning process and offer concrete points of reference linked to the development of systems thinking skills. Thus, the questions served as scenarios in which to share with the students the objective of each phase and the reflections, comments or contents that should be included therein.

Table 2.
Phases of the training activities on Climate Change and systems thinking

System Thinking Skills	Exemplification of questions and activities
Identify components and natural processes involved	What is the greenhouse effect? What happens when greenhouse gases increase? Activities: virtual simulation of the greenhouse effect
Identify the dynamic relationships between the natural and anthropogenic components of the system, relating them to the alteration of the processes (feedback)	What is the effect of the anthropogenic CO2 increase on the atmosphere? And on the oceans? Is it possible that humans are changing climate and ocean chemistry? Activities: interactive activities of the I2Sea website
Integrate problems within the Earth System.	What is Global Environmental Change? Activities: analysis of the IPCC reports
Explain hidden dimensions of the system.	What are the real consequences of Climate Change for people? Does it affect women and men in the same way? Activities: analysis of news on the unequal impact of CC by gender and by country
Think temporally: retrospection and prediction.	What is known as the Great Acceleration? What characterizes the Anthropocene? What differentiates it from the Holocene? Activities: analysis of Steffen's graphs (2015)

As for the teachers who gave the training, it should be noted that they have specific training in the systemic processes that are part of Global Environmental Change. These teachers acted as guides and moderators of the process, mainly intervening in classroom discussions.

4. Methodology

This research is based on a case study, which is a flexible methodology (Hyett et al., 2014) that allows the researcher to investigate a phenomenon within a real context, on the basis of which quantitative and qualitative approaches can be combined (Rowley, 2002). Within this framework, the analysis of the results was carried out using a mixed approach (Plano-Clark and Ivankova, 2015). Thus, a content analysis (Bardin, 1996) of the products obtained (videos) in the didactic sequence was carried out, in order to subsequently analyse these results in a descriptive quantitative way.

4.1 Sample

The study involved a sample of second year students enrolled in the Primary Education programme at the University of Vigo, Pontevedra, Spain. There were 82 students in total, all from the same classroom. They were mainly women (75 women and 7 men), with an average age of 20 and worked together in 16 teams of similar size. The research was carried out in the classroom. The students were informed that the results would be collected to conduct the study, and their participation was voluntary. It is worth noting, for the interest of this study, that the participating students had no previous specific training in systemic competence and little or no training in climate sustainability, as these are not currently included in the curricula of this degree programme.

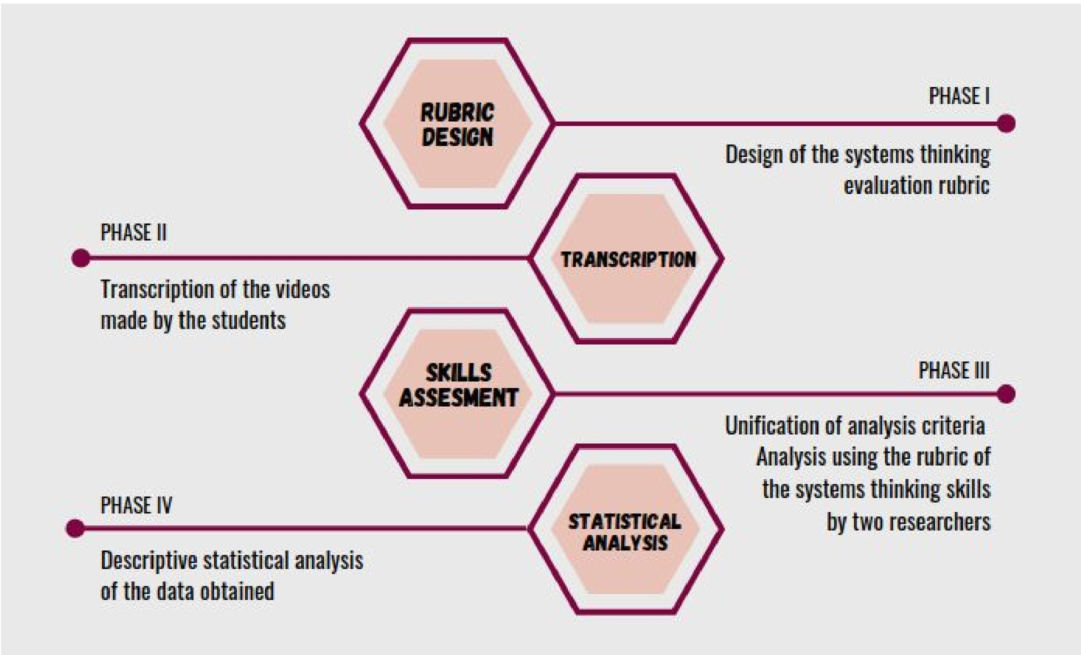
Regarding the consent of the research participants, the students were informed at the beginning of the study and their voluntary participation was requested. It should also be noted that they were not asked at any time for sensitive personal information and that their data were not stored.

4.2 Process

After the training activity, the results were evaluated by analysing the content of the 16 videos created by the students to assess the level of complexity and achievement of systems thinking skills. The process was divided into 4 phases as shown in Figure 1:

Figure 1

System thinking rubric levels



4.3 Research instrument

On the basis of the pertinent literature, an evaluation rubric on systems thinking in the context of a training activity on climate change was designed in this study (Table 2). The aim was to identify and assess the presence of the skills associated with this competence.

The construction of this rubric took place within the framework of an expert research group composed of professionals from the fields of sustainability education, psychology and technology. Thus, in the elaboration of the rubric, key issues of System Dynamics, have been considered. In its development, special attention was given to the characteristics defined by

Ben-Zvi Assaraf and Orion (2010) for systems thinking in the context of the Earth system, in addition to other skills needed to understand socio-environmental problems holistically (Yoon et al., 2017; York et al., 2019; Bielik et al., 2023; Crofton, 2000; Hung, 2008; Dyehouse et al., 2009 Wiek et al., 2011; Arnold and Wade, 2017; Mehren et al., 2018; Feriver et al., 2019; Rockström et al, 2023). On the basis of this framework, two areas were considered for the construction of the rubric: on the one hand, the characteristics associated with systems thinking (structure, processes and behaviour) and, on the other hand, the knowledge necessary to understand the interaction between natural and human systems on different scales and its implications for the life of people and the planet.

The following phases were followed to design the rubric:

I. Review of the literature on systems thinking, systems theory and key competences in sustainability.
II. Initial design of the rubric seeking to contextualize this literature within the framework of Global Environmental Change, taking the CC process as a paradigmatic example.
III. Review of the rubric by staff with expertise
IV. The original rubric was written in Spanish. To ensure accuracy during translation, the services of a specialist experts were used to check the accuracy of the language change.

Based on a review of literature, this rubric is made up of five Systems Thinking Skills, which are specified in fourteen analysis sub-skills, to make the instrument more solid. Moreover, three hierarchical levels of complexity have been established: level 1, or basic complexity (STS_1 and 2 skills), which includes the identification of components and processes and the dynamic relationships between them (Ben-Zvi Assaraf and Orion, 2010; Hung, 2008; Arnold and Wade, 2017; Mehren, 2017; Lavi, 2019); level 2, or intermediate complexity (STS_3 skill), which includes the ability to make generalizations and understand the system as a whole (Ben-Zvi Assaraf and Orion, 2010; Hung, 2008; Arnold and Wade, 2017; Mehren, 2017; Catalina Foothill School, 2018, Feriver et al., 2019; Lavi and Dori, 2019); and level 3, or advanced complexity (STS_4 and 5 skills), related to the understanding of the hidden dimensions of a system and the ability to think temporally and spatially (Hung, 2008; Feriver et al., 2019; Lavi and Dori, 2019). However, other characteristics such as intention to act (Mehren et al., 2017) or self-regulation and reflection (Catalina Foothills Schools, 2018) were not included, as we consider these dimensions to be part of other key competences (Wiek et al., 2011).

Finally, each skill has been divided into categories of analysis, in which these components of systems thinking have been described in relation to climate change and its relationship with the social and economic sphere on different scales (temporal and geographical), in a manner rarely addressed in the literature. Thus, this problem is dealt with in interrelation with Global

Environmental Change, linking its origin to anthropogenic causes, especially in relation to the exponential increase in human activities and their form of development (Chomsky and Pollin, 2020). Aspects related to interspecies, intragenerational (between countries, communities and individuals) and intergenerational justice are also included (Rockström et al., 2023), introducing the temporal dimension of the alterations and the concern for these future consequences for human and planetary well-being (Wiek et al., 2011).

These categories are rated on a scale of 1 to 5, referring to the level of achievement of each category of analysis (see Table 3).

Table 3.
System Thinking Rubric Levels

Hierarchy of levels of complexity	System Thinking Skills and Relation to the Climate Change	Categories of analysis
Basic complexity	**STS_1.** Ability to identify natural components and processes involved in CC	**STS_1a.** They **identify** the most important **natural components** involved in CC**.**
		STS_1b. They **identify** the most important **natural processes** involved in climate change.
	STS_2. Ability to establish the dynamic relationships between the natural and anthropogenic components and processes of the system, relating them to the modification of the processes	**STS_2a.** They **establish dynamic equilibrium relationships in the processes**
		STS_2b. They **link variations** in system components to their **origins** and their **consequences**, either quantitatively or qualitatively.
		STS_2c. They link the **exponential increase** in human activities to the serious **disruption** of the biophysical and social system.
Intermediate complexity	**STS_3.** Ability to make generalizations	**STS_3a.** They identify CC as a **global process**, and even relate it to global environmental change.
		STS_3b. They present the system as a whole. They present CC as **an interrelated process in its origin and in its evolution with other processes.**
		STS_3c. They express **concern** about the severity of the consequences of these global disruptions and point to the structural changes needed.
Advanced complexity	**STS_4.** Ability to understand the hidden dimensions of the system	**STS_4a.** They explicitly talk about the link between the **socio-economic model and the origin** of CC
		STS_4b. They make visible **hidden dimensions** of these processes related to the effects on **human activities** (not only on the environment) and people's **welfare**.
		STS_4c. They make visible hidden dimensions of **inequity-related** processes
	STS_5. Ability to think temporally: retrospection and prediction	**STS_5a.** They explain that CC **does not occur in a linear way**, often being characterized by abrupt and potentially irreversible changes.
		STS_5b. They explain the **temporal dimension of the changes** (delay) in the processes involved.
		STS_5c. They indicate concern about the **future effects** of current actions on the life of the planet and people.

4.4 Data collection and processing

Once the subject of analysis (Table 2) had been determined, an initial meeting was held to unify criteria. Within this framework, common coding rules were established for each subskill. Subsequently, two researchers used the rubric to assess the activities of each of the groups.

Kappa coefficients and intraclass correlation coefficients can be used to assess the interrater reliability of ordinal rating scales (de Raadt et al., 2021). To determine whether there is adequate agreement between their ratings, we chose to calculate the Intra Class correlation coefficients (ICC) for each of their ratings using the statistical software SPSS version 20 for Windows. This option was chosen over the different variants of Kappa coefficients, given the criticisms they have received in literature (Vanbelle, 2016). Since all the raters assess all the activities, and reliability is calculated on the basis of each measure, ICC form *two-way mixed effects, consistency, single rater/measurement* (McGraw and Wong, 1996) is used.

To analyze each item of the rubric, the mean of the ratings of the two raters is used. In addition, the mean score of the values of the five System Thinking Skills (STS_1 to STS_5) is calculated and their distribution presented in the form of boxplots.

5. Results

In order to identify the level of performance of the subskills of the future teachers, the researchers analysed the verbalizations that appear in the videos. A selection of the examples is shown below in Table 4.

Table 4.
Selection of the examples

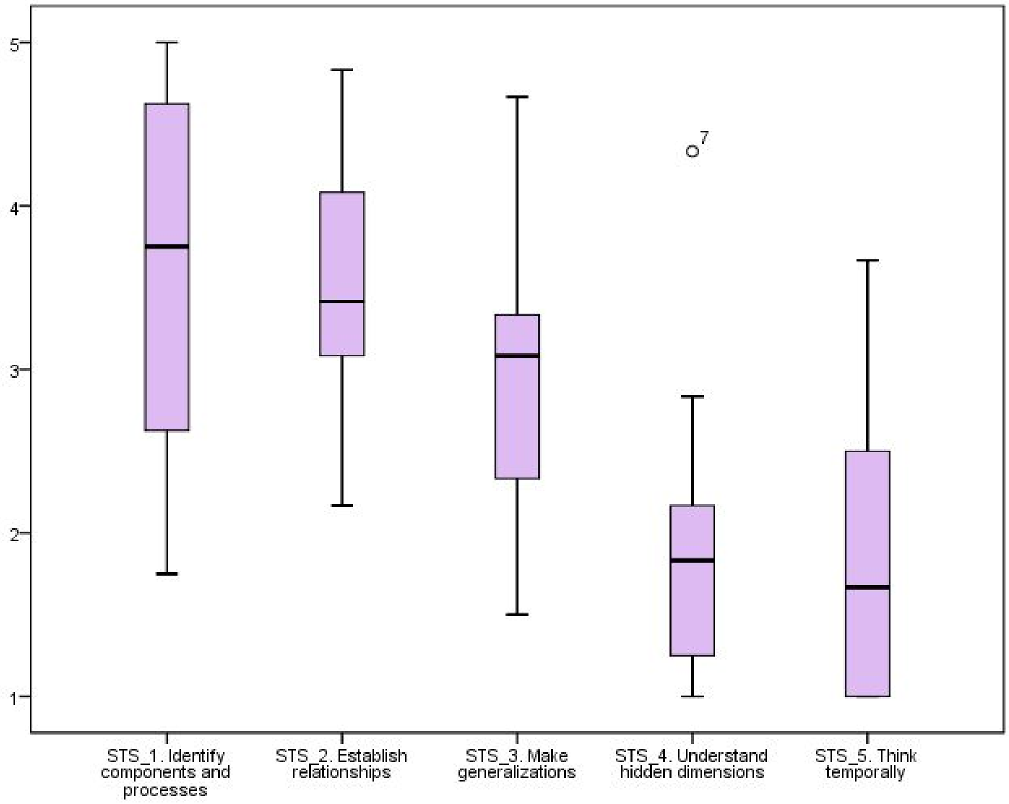
System Thinking skills	Examples
STS_1	Team 1's students identify components such as "carbon dioxide", "atmosphere", "energy" or "temperature"
STS_2	Team 15's students state "the balancing agent is the natural greenhouse effect that makes life on Earth possible"
STS_3	Team 3's students identify Climate Change as a global process by mentioning "global environmental change" and indicating that this is "the set of all the harmful actions being carried out by human beings that generate certain effects on our planet"
STS_4	Team 15's students point out that it is necessary to ask ourselves certain questions in relation to our lifestyle such as "where do our clothes come from, where and who produces them?", relating to consumerism and production models
STS_5	Team 15's students state that "this change is very fast and identifies human beings as those responsible"

With the aim of systemizing these findings, a statistical analysis, in the form of a quantitative descriptive analysis, was subsequently performed. To this end, as there are 14 items in the rubric, 14 ICC values of consistency are obtained, ranging from 0.693 to 0.951. According to Cicchetti (1994), values between 0.60 and 0.74 are good, and between 0.75 and 1.00, excellent, and according to Portney and Watkins (2000), values between 0.50 and 0.75 indicate moderate reliability, and above 0.75, good. Therefore, the reviewers have an adequate level of agreement in their assessments.

The results obtained show different levels of performance in the complexity hierarchy of systems thinking. As can be seen in Figure 2, the capabilities shown decrease as we approach higher levels of complexity, with averages close to 3.5 at the basic level (STS_1 and STS_2) and dropping to averages below 2 at the advanced level (STS_4 and STS_5).

Figure 2

Boxplots depicting the hierarchy of levels of systemic thinking.



With regard to the specific categories of analysis (see Table 5), it may be of interest to note that STS_2b is the item with the highest score (4.34), i.e., students are able to correctly link the variations of the system's components with their origins and consequences. High averages are also obtained for the items related to the ability to identify the most important components and natural processes involved in Climate Change (STS_1a and 1b). Likewise, students, in general, seem to be able to establish dynamic equilibrium relationships between the different natural and anthropogenic processes and are able to present the system as a whole, interrelated in its origin and in its evolution with other processes (STS_3c).

The opposite is true for the items characterizing advanced complex thinking skills. Despite the training action carried out, the students have major difficulties in explaining the temporal dimension of the changes (delay) in the processes involved (STS_5b) and that this process does not occur in a linear way, but that on many occasions there are abrupt changes that may become irreversible (STS_5a). Furthermore, they have problems in recognizing the hidden dimensions of Climate Change in relation to inequality and the effects on human activities (not only on the environment) and people's well-being (STS_4b and 4c).

Table 5.
Mean scores and standard deviations (SD) obtained in the categories of analysis.

Categories of analysis	Mean	SD
STS-1b.	3.75	1.11
STS-1b.	3.37	1.30
STS-2a.	3.78	1.38
STS-2b.	4.34	0.77
STS-2c.	2.41	1.53
STS-3a.	2.19	1.33
STS-3b.	3.66	0.91
STS-3c.	2.97	1.22
STS-4a.	2.41	1.50
STS-4b.	1.84	1.29
STS-4c.	1.41	0.92
STS-5a..	1.84	1.16
STS-5b.	1.34	0.79
STS-5c.	2.25	1.29

Finally, it should be noted that four of the categories analyzed have values between 2 and 2,5, for example, the ability to relate the exponential increase in socio-economic indicators or its direct relationship to the exponential increase in environmental indicators (STS_2c) and its relationship with the dominant socio-economic model (STS_4a). Medium-low values are also obtained in the ability to identify climate change as a global process (STS_3a) as well as in their ability to think temporally, especially when it comes to making predictions (STS_5c).

6. Discussion

Systems thinking is an essential skillset to address the challenges of sustainability today (UNESCO, 2017; Voulvoulis et al., 2022). In order to address the consequences of a development model that endangers the life of the planet, it is necessary to move towards holistic conceptualisations of reality (Bauman, 2013; Morin and Petit, 2011). But as literature shows (York et al., 2019), systems thinking is not a natural way of thinking for human beings and teacher training in this regard often shows significant weaknesses. Thus, studies show that systems thinking is not being properly developed in educational programmes, especially in the context of climate change (Sterman and Sweeney, 2007; Roychoudhury et al., 2017).

Climate Change is not an isolated socio-environmental problem but is occurring in the context of Global Environmental Change, where other problems such as biodiversity loss and ocean acidification are closely related (Steffen et al., 2015). To understand the current situation, it is essential that students can understand the Earth system as a whole. Furthermore, education for sustainability requires a holistic understanding of the environment, where there are complex relationships between economics, social issues, and the environment. Thus, it is necessary for students to relate the exponential increase in human activities to these alterations of the biophysical and social system. And to improve people's decision-making in this framework, it is essential that they understand not only the consequences on the environment but also on human activities and well-being. In addition, they must consider the (feedback and non-linear temporal) processes involved in how decisions made now affect the future. Students must therefore understand that the consequences (direct and indirect, short and long-term) threaten current ways of life and even the survival of the human species.

The research results show that future teachers are able to reach the basic levels of complexity that define systems thinking, that is, they are able to identify the main components and natural processes involved in Climate Change and are able to establish dynamic relationships between the natural and anthropogenic elements of the system (such as the alterations of the greenhouse effect). They are also able to understand Climate Change as a whole, interrelating its origin and evolution with other processes, such as ocean acidification, sea level rise or biodiversity loss (IPCC, 2022). Similar results have been found in proposals by, for example, Roychoudhury et al. (2017) based on asking relevant questions. Their students were able to identify not only the components and structures that make up the climate system, but also to explain, describe and quantify the dynamics that occur in a natural and complex system such as climate.

But the more complex the skill required, the lower the level of development shown by the students. After the proposal was carried out, students continued to show significant difficulties in thinking temporally about Climate Change. According to Sterman and Sweeney (2007), even well-educated people with a solid STEM background fail to understand the more complex features, such as feedback or time delays and non-linearities. Developing these highly complex skills involves being able to establish cause-effect links between their dynamic relationships, understand how abrupt changes and delays occur, and make projections for the future (Ben-Zvi Assaraf and Orion', 2005; Roychoudhury et al., 2017).

Another question of great interest relates to understanding the social dimensions involved in the system. After completing the didactic proposal, students still have problems in identifying the serious effects of climate change on human well-being and activities, as the impacts on the environment are more often highlighted without relating them to the consequences on people's real lives, now and in the future (Oberauer et al., 2022). Furthermore, the data seem to show the difficulties that students have in assessing the inequality involved in the origin and consequences of this socio-environmental problem. This is a key element for understanding climate change as a process on a local and global scale, whose socio-environmental implications have different impacts depending on people's ability to adapt and recover.

The results obtained are positive, considering that this is an isolated training action within the educational program for teacher training. As recommended by Ben-Zvi Assaraf and Orion (2005), the development of systems thinking in the context of the Earth System should be carried out in sequential stages in a hierarchy of complexity, as the cognitive skills developed at each stage serve as a basis for the development of the following higher order skills. In this way, it would be necessary to continue working on similar proposals to which an increasing degree of complexity should be added, stressing skills that are still in the development phase, such as temporal thinking in a systemic process and the assessment of the hidden dimensions of the socio-environmental problem. Another issue is to decide what level of complexity needs to be reached in the different collectives. Teachers at early learning level do not have to develop systems thinking in the same way as an ecologist, but it is important that they are able to understand how systemic processes work to be able to integrate this knowledge into their daily practice. There are other groups where the management of complex processes is key, and that is why it is increasingly used in in different fields (Kendall et al., 2019). For example, as technological systems become larger, more complex and multidisciplinary, there is a growing demand for engineers with systems thinking capabilities.

In this regard, it is important to highlight the evaluation framework designed to guide training activities for developing systems thinking on climate change. The results enable assessment of the didactic potential of the rubric created as a reference for designing future training proposals. Its use can help focus on the different skills required to understand climate change as a natural system that seriously affects life on the planet.

7. Conclusions and educational implications

Climate education is a fundamental part of tackling the current crisis (UNESCO, 2021). However, its educational approach is very challenging because climate is a complex, interconnected and dynamic system.

To this end, an innovative didactic sequence was designed and implemented, focusing on the formulation of motor questions that guide the development of the skills inherent to systemic competence. Due to the absence of precise assessment tools for measuring the presence and development of key competencies, a new rubric on systems thinking was created. The rubric demonstrated its potential to drive this process. It was contextualised within Global Environmental Change and focuses on Climate Change, to assess its ability to understand the interaction and interrelation with other environmental problems, and the interdependence between the human and natural dimensions. Its use again revealed how the development of systems thinking is a complex learning process that requires sequential training actions focused on its most essential aspects. Thus, it is necessary to integrate elements that facilitate the development of more difficult subskills into the training proposals. To reinforce the understanding of the hidden dimensions, it seems appropriate to include the treatment of real data that favour the identification of the relationships between different geographical or social contexts and the relationships between daily actions and current and future socio-environmental effects on human activities. To develop temporal thinking, the use of ICT applications that foster the approximation of future realities in terms of current/possible emissions can be useful. Without discounting the potential of new technologies such as artificial intelligence (AI).

Although the obtained results are relevant, it is necessary to consider that this is a pilot study, and it has inherent limitations due to the methodology used (Plano-Clark and Ivankova, 2015), the size of the sample and its characteristics, as for example the influence of groupthink. To continue this line of research, it would be of interest to increase the sample and integrate new research techniques (interviews, questionnaires, discussion groups) that allow the results obtained to be refined, as well as to extend the study to new groups. Furthermore, due to the nature of the study, we were unable to research the development of competences in systems thinking, with a pre-test and post-test study, as the pupils had no previous training in systems thinking contextualised in Climate Change.

Moreover, it should not be forgotten that a transformative action-oriented pedagogy aims to educate people capable of making conscious and fair decisions, which require an understanding of systemic processes (UNESCO, 2017), but which also require the interdependent mobilisation of other key competences such as normative competence or anticipatory competence (Brundiers et al., 2021). It would therefore be important to continue this research by studying the interrelation of the development of systems thinking with other key competences in sustainability such as interpersonal, anticipatory or normative competence (Wiek et al., 2011). The educational and societal transformation towards sustainability implies that teachers develop the necessary commitment and these competences (Leal Filho et al., 2021). As these authors note this challenge entails not only professional development in education and teaching, but also in respect of managing of institutions, curriculum development and monitoring and assessment of learning success. It is essential to incorporate this skill into the curriculum through interdisciplinary, participatory, and project-based approaches that are linked to complex realities, as suggested by Sleurs (2008), when developing educational policies. Teachers' curricula should support the development of this competence, following a scaffolding that facilitates progression to higher levels of complexity.

The proposed framework allows us to rethink the way in which we teach and learn about global problems, how key competences are integrated and how higher education can promote climate education that favors the training of a citizenry that is competent in its search for systemic solutions.

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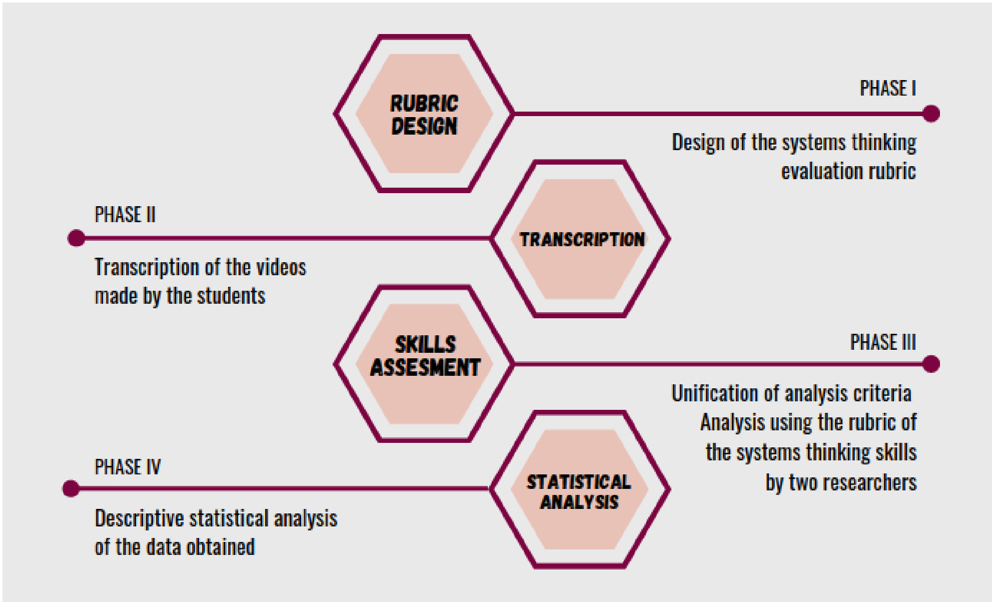

Figure 1
System thinking rubric levels

59x35mm (300 x 300 DPI)

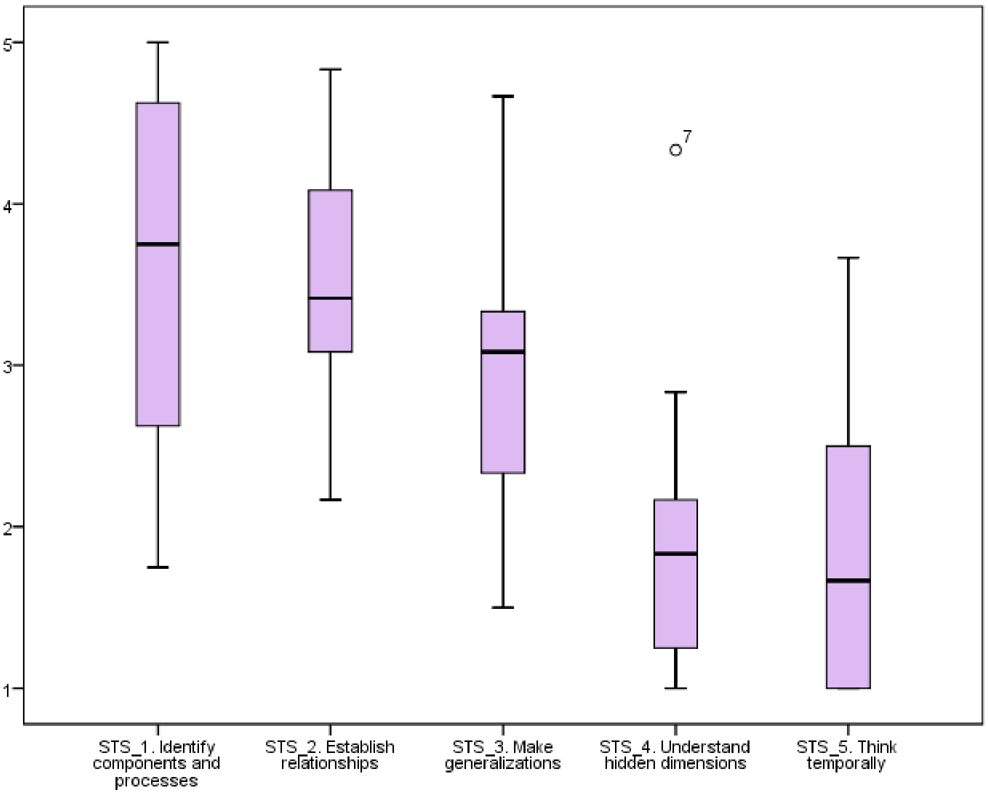

Figure 2
Boxplots depicting the hierarchy of levels of systemic thinking

220x176mm (72 x 72 DPI)

Table 1.

Characteristics/dimensions of the different rubrics and conceptualisations of systems thinking

Author	**Assaraf (2010)**	**Hung (2008)**	**Arnold (2017)**	**Mehren (2017)**	**Catalina Foothills School (2018)**	**Feriver (2019)**	**Lavi (2019)**
Context	*Junior high school students Israel*	*Master students USA*	- *USA*	*Secondarystudents Germany*	*Grades K-2 USA*	*Preschool student with university parents Germany and Turkey*	*Science and engineering teachers Israel*
Components and Structure	Identify the components and processes within the system Identify relationships among the system's components Organize the systems' components and processes within a framework of relationships	Identification of crucial variables Linearity Interconnectivity	Content (What's in the system) Structure (How's it organized)	System organisation (structure, limits)			Structure (main object and its subobjects structural links)
Behaviour	Make generalizations Identify dynamic relationships within the system Understand the hidden dimensions of the system Understand the cyclic nature of systems Think temporally	Cause-effect relations (causal-loop) Feedback processes (positive and negative) Dynamics processes Contextualization Underlying mechanism (explanatory knowledge)	Behavior (What happens when content and structure interact)	System behaviour (emergence, interaction, dynamics)	Change over time Interdependencies Consequences System as Cause Leverage Actions Big Picture	Hidden dimension Seeing the whole Recognition of causality Understanding systems mechanisms Identifying and understanding feedback Future prediction Understanding dynamic behavior Identifying intervention points	Behaviour (procedural links, complexity levels, procedural sequence)
Others			Mindset (How to approach systemic problems)	System-adequate intention to act (prognosis) System adequate action (regulation)	Self-Regulation and Reflection		Function (expected outcome / intendedpurpose; main function)

Table 2.

Phases of the training activities on Climate Change and systems thinking

System Thinking Skills	Exemplification of questions and activities
Identify components and natural processes involved	What is the greenhouse effect? What happens when greenhouse gases increase? Activities: virtual simulation of the greenhouse effect
Identify the dynamic relationships between the natural and anthropogenic components of the system, relating them to the alteration of the processes (feedback)	What is the effect of the anthropogenic CO2 increase on the atmosphere? And on the oceans? Is it possible that humans are changing climate and ocean chemistry? Activities: interactive activities of the I2Sea website
Integrate problems within the Earth System.	What is Global Environmental Change? Activities: analysis of the IPCC reports
Explain hidden dimensions of the system.	What are the real consequences of Climate Change for people? Does it affect women and men in the same way? Activities: analysis of news on the unequal impact of CC by gender and by country
Think temporally: retrospection and prediction.	What is known as the Great Acceleration? What characterizes the Anthropocene? What differentiates it from the Holocene? Activities: analysis of Steffen's graphs (2015)

Table 3.

System Thinking Rubric Levels

Hierarchy of levels of complexity	System Thinking Skills and Relation to the Climate Change	Categories of analysis
Basic complexity	**STS_1.** Ability to identify natural components and processes involved in CC	**STS_1a.** They **identify** the most important **natural components** involved in CC.
		STS_1b. They **identify** the most important **natural processes** involved in climate change.
	STS_2. Ability to establish the dynamic relationships between the natural and anthropogenic components and processes of the system, relating them to the modification of the processes	**STS_2a.** They **establish dynamic equilibrium relationships in the processes**
		STS_2b. They **link variations** in system components to their **origins** and their **consequences**, either quantitatively or qualitatively.
		STS_2c. They link the **exponential increase** in human activities to the serious **disruption** of the biophysical and social system.
Intermediate complexity	**STS_3.** Ability to make generalizations	**STS_3a.** They identify CC as a **global process**, and even relate it to global environmental change.
		STS_3b. They present the system as a whole. They present CC as **an interrelated process in its origin and in its evolution with other processes.**
		STS_3c. They express **concern** about the severity of the consequences of these global disruptions and point to the structural changes needed.
Advanced complexity	**STS_4.** Ability to understand the hidden dimensions of the system	**STS_4a.** They explicitly talk about the link between the **socio-economic model and the origin** of CC
		STS_4b. They make visible **hidden dimensions** of these processes related to the effects on **human activities** (not only on the environment) and people's **welfare**.
		STS_4c. They make visible hidden dimensions of **inequity-related** processes
	STS_5. Ability to think temporally: retrospection and prediction	**STS_5a.** They explain that CC **does not occur in a linear way**, often being characterized by abrupt and potentially irreversible changes.
		STS_5b. They explain the **temporal dimension of the changes** (delay) in the processes involved.
		STS_5c. They indicate concern about the **future effects** of current actions on the life of the planet and people.

Table 4.
Selection of the examples

System Thinking skills	Examples
STS_1	Team 1's students identify components such as "carbon dioxide", "atmosphere", "energy" or "temperature"
STS_2	Team 15's students state "the balancing agent is the natural greenhouse effect that makes life on Earth possible"
STS_3	Team 3's students identify Climate Change as a global process by mentioning "global environmental change" and indicating that this is "the set of all the harmful actions being carried out by human beings that generate certain effects on our planet"
STS_4	Team 15's students point out that it is necessary to ask ourselves certain questions in relation to our lifestyle such as "where do our clothes come from, where and who produces them?", relating to consumerism and production models
STS_5	Team 15's students state that "this change is very fast and identifies human beings as those responsible"

Table 5.

Mean scores and standard deviations (SD) obtained in the categories of analysis.

Categories of analysis	**Mean**	**SD**
STS-1b.	3.75	1.11
STS-1b.	3.37	1.30
STS-2a.	3.78	1.38
STS-2b.	4.34	0.77
STS-2c.	2.41	1.53
STS-3a.	2.19	1.33
STS-3b.	3.66	0.91
STS-3c.	2.97	1.22
STS-4a.	2.41	1.50
STS-4b.	1.84	1.29
STS-4c.	1.41	0.92
STS-5a..	1.84	1.16
STS-5b.	1.34	0.79
STS-5c.	2.25	1.29