**Interdisciplinary Journal of Environmental and Science Education**
2021, 17(1), e2226
ISSN: 2633-6537 (Online)
https://www.ijese.com

# The Use of The Lesser Kestrel's Life Cycle to Enhance Elementary School Children's Understanding of Complex Systems

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**Citation:** Gal, A., Gan, D., & Ben Zvi-Assaraf, O. (2021). The use of the lesser kestrel's life cycle to enhance elementary school children's' understanding of complex systems. *Interdisciplinary Journal of Environmental and Science Education*, *17*(1), e2226. https://doi.org/ 10.29333/ijese/ 9152

**ARTICLE INFO**

Received: 22 June 2020

Accepted: 14 October 2020

**ABSTRACT**

Understanding the complexity of ecological system is crucial if one is to achieve a proper understanding of what they are and how they function. This study followed an environmental education program designed to introduce fifth grade students from a highly rural community to the world of ornithology and to the importance of maintaining the biodiversity of birds in nature. Its goal was to explore the program's influence on the development of these students' system thinking skills in the context of the life-cycle of the Lesser Kestrel (LK). Students' perceptions of system complexity were tracked using the repertory grid technique, which takes the form of a highly structured interview in which constructs represent participants' interpretations of various elements and the relationships between them. The results indicate that these fifth graders developed a significantly complex view of the LK's ecosystem. Participation in the program developed the ability of some of the students to generalize and to identify changes that occurred in the birds' ecosystem over time. Design elements such as longitudinal real-time observations and learning about the kestrel's life-cycle while examining its interaction with its environment were found to be important for system thinking development. These cognitive tools may enable students to better cope with complex, biodiversity-related environmental issues in the future.

**Keywords:** student learning, cognitive development, biology, environmental education, primary education, complex systems

## INTRODUCTION

The subject of ecology has grown in prominence over the past decade due to the understanding that maintaining biodiversity is an integral part of the effort to promote sustainable development. Biodiversity is important not only for its own sake but also in terms of its contribution to humanity, due to the many services that we rely on from various species as part of their regular interaction with the ecosystem. Birds are an important bio-indicator of biodiversity and of the ecosystem's health. They are found in various types of habitats and play an important role in the structure and function of ecosystems as they have an important role in maintaining the balance of many ecosystems by providing a variety of ecological services (Latumahina & Mardiatmoko, 2019). These services include functions such as seed dispersal, flower pollination, and the regulation of the insect population (Jones & Sieving, 2006; Klein et al., 2007), constitute a valuable resource in economic, cultural, aesthetic, scientific and educational terms. Consequently, the centrality of birds in the ecosystem requires developing complex system thinking in science education.

Recent trends in science education are to engage students through the nature and practice of science in the context of their own world (NGSS, 2013). The complex system ideas on which this study focuses are examples of such cross-cutting concepts. Complex systems are prevalent in many scientific fields, as in the field of biology. Complex systems are found within individual cells, in which complex molecular networks contact signals from the extra-cellular environment, thus invoking intracellular responses (Chasman et al., 2016). Complex systems are also found in individual organisms on the physiological level, maintaining homeostasis in a variety of dimensions, such as blood sugar and body weight (Rosenbaum & Leibel, 2016). On an even larger scale, interactions between organisms form additional complex systems such as social insect colonies (e.g., ants), which are generated by interactions between organisms, each of which is a complex system in its own right (Greenwald et al., 2015). Such ecological system are typically dynamic (Anand et al., 2010), and are often held in a state of equilibrium with other interdependent systems (Wallington et al., 2005), so that the interactions within and between them may be unpredictable (Thébault & Loreau, 2006). If we interrupt this network of interconnectivity we might witness notable effects. (Stewart, 2012). Understanding the complexity of ecological system is therefore crucial to a proper understanding of what they are and how they work (Snapir et al., 2017).

Recently, a novel approach to science education spearheaded by the Next Generation Science Standards (NGSS, 2013) has posited that science education should develop scientific literacy, i.e. students' ability to take a broad look at – and think intelligently about – various topics in the realms of science and technology, as well as their social implications. According to this approach, science education should include references to socio-scientific issues (SSI) which "*represent real problems faced by scientists and other citizens, whose solutions remain undetermined and are not problems merely in the context of classroom explorations*" (Zeidler & Sadler, 2008, p.201).

Environmental education (EE) is designed to provide students with the knowledge and experience they need to actively participate in the attempt to find solutions to various local social and environmental problems (Smith & Sobel, 2010; Smyth, 2006). Thus, science education that includes social implications and socio-scientific issues is part of EE. Since the roots of all EE lay in a naturalistic approach (Sauvé, 2005), our study uses this approach as its conceptual framework and theoretical underpinning.

The study presented here focuses on the implementation of an EE program which used the topic of ornithology (Can et al., 2017) to introduce children from a rural community to the world of the scientific observation of birds, and through this to the importance of maintaining the biodiversity of birds in nature. Therefore, the aim of the study was to investigate the influence of an EE program (named the Lesser Kestrel program) on the development of elementary school students' system thinking skills in the context of bird ecology. Our research questions were as follows:

(1) How do students' perceptions of complexity change following their participation in the Lesser Kestrel (LK) program? The complexity is examined via three sub-questions:

- What are the students' abilities in identifying the components and processes that exist in the LK ecosystem?
- What are the students' abilities in identifying interrelations within the LK ecosystem?
- What are the students' abilities in identifying both patterns in the system and the time dimensions of the LK ecosystem?
- (2) Which characteristics of the unique learning environment are expressed by elementary school students' explanations of phenomena related to eco-ornithology?

## THEORETICAL BACKGROUND

### What are Complex Systems?

Complex systems are made up of many elements (often referred to as "*agents*") that interact with each other and with their environment. The interactions of numerous elements result in a higher-order, or collective, behavior. These systems self-organize in logical global patterns, despite the fact that systems as such, are not regulated through central control (Holland, 1995). A focal concept in our work and a fundamental property of complex systems is emergence, which is the process by which collective behavior arises out of individuals' properties and interactions, usually in non-obvious ways. The properties of a system's patterns cannot be reduced merely to the properties of its individual elements (Bar-Yam et al., 1998; Holland, 1995). In fact, these patterns are often counter-intuitive and unexpected (Wilensky & Resnick, 1999).

Achieving the 'scientific ways of knowing' to which science education aspires, learners need to learn how to investigate complex system phenomena, and to think about them critically (Hmelo-Silver & Azevedo, 2006; Jacobson & Wilensky, 2006). However, learning about complex systems and their components' interdependence may be difficult due to the multi-dynamic processes occurring within it. The study of complex systems poses challenges for both learners and educators (Ben Zvi - Assaraf & Orion, 2005; Hmelo-Silver & Pfeffer, 2004; Plate, 2010) which were implemented in order to collect the data concerning the students' knowledge and understanding before, during, and following the learning process. The findings indicated that the development of system thinking in the context of the earth systems consists of several sequential stages arranged in a hierarchical structure. The cognitive skills that are developed in each stage serve as the basis for the development of the next higher-order thinking skills. The research showed that in spite of the minimal initial system thinking abilities of the students most of them made some meaningful progress in their system thinking skills, and a third of them reached the highest level of system thinking in the context of the hydro cycle. Two main factors were found to be the source of the differential progress of the students: (a Several studies have shown that understanding the structural and behavioral aspects of complex systems is challenging for science students (Jacobson & Wilensky, 2006), since understanding these systems requires not only contemplating their parts in the context of the whole system, but also examining their interactions with other complex systems surrounding them. Developing a broad and logical perception of the constructs in systems and of the multi-variable web of relationships between them is challenging since these relationships are not intuitively obvious (Duncan & Reiser, 2007; Jacobson, 2001). Relationships across different levels of complex systems are also often implicit, with subsidiary causality (Hmelo-Silver & Azevedo, 2006; Jacobson, 2001).

Studies addressing elementary school students report that students do not see ecosystem functioning as an interrelated whole. Furthermore, when describing relationships in nature such as food web, children tend to use simple linear causality in which only one population directly affects another, rather than several different pathways forming the web (Grotzer & Basca, 2003). In view of this tendency toward linear perception, Grotzer and Basca (2003) point out that there is a need to provide students with structural knowledge referring to "*the way that experts in a domain deal with the foundational concepts, such as causality or categorization, that impact how we frame experience or information*" (p. 27). Research shows that fourth grade students do not usually think about water in dynamic, cyclical systems. They show little awareness of connections between water in one location and water in other locations; rather, they tend to focus on the atmospheric components of the water cycle, disregarding processes related to groundwater, surface water, and water in biotic systems. Furthermore, students tend to view the water cycle as a textbook representation and do not connect the textbook version of the water cycle to their understanding of water in their own geographic locations (Ben Zvi - Assaraf & Orion, 2010) during, immediately after, and 6 years after completing a year long systems-based learning program. The employed research tools included observations, semi-structured interviews, and a number of \"concept viewing\" tools (drawings, concept maps, and repertory grids. Although their initial ideas about water are often naive and unconnected, studies by Endreny (2010) and Ben-Zvi Assaraf and Orion (2010) show that students can develop more connected, sophisticated and systems-oriented ideas about water through instruction. Understanding the structural and behavioral properties of complex systems is a challenging cerebral attempt for students studying science. However, EE may provide a framework for achieving it by integrating the local physical environment with community and authentic environmental challenges (Endreny, 2010).

## RESEARCH SETTING

This study was conducted in a relatively small elementary school in northern Israel located in a rural area, which is the habitat of the smallest falcon in Israel, the Lesser Kestrel (Falco naumanni). The LK population breed in the Southern Palearctic region, with its wintering grounds located in sub-Saharan Africa (IUCN, 2018). In the middle of the 20th century, the LK population experienced a marked decline in its western Palearctic breeding range. This decline has been attributed to changes in land use, use of pesticides, abundance and quality of prey, extensive urban development, predation on either eggs or nestlings, and reduction in the number of traditional nest sites (e.g., in cavities in roofs) which all influence breeding success (Bobek et al., 2018; Gal & Yosef, 2018; Liven-Schulman et al., 2004).

For instance, the Spanish population, representing 60–70% of the LK western European population, was comprised of about 100,000 breeding pairs in 1960 but was down to 12,000 pairs in 2000. Trends such as these have been noted for other populaces in Israel (Liven-Schulman et al., 2004), and the species became almost extinct in a number ofs Mediterranean countries, e.g. France in the early 1980s (Mihoub et al., 2010)accurate estimation of whether climatic fluctuations impact on population demographic parameters is needed for adequate management, especially for migratory species. We present a capture-recapture analysis linking survival rates of the vulnerable Lesser Kestrel (Falco naumanni. The recovery of major Iberian populations through conservation actions has improved the conservation status of the species from 'vulnerable' to 'least concern' (IUCN, 2018). Yet , their conservation status is unstable beyond the Iberian Peninsula and obliges further investigation, especially in southern and eastern Europe, the Mediterranean (Di Maggio et al., 2013), and Israel (Gal & Yosef, 2018).

### Environmental Education – The Naturalistic Approach

The LK program was based on EE focused on outdoor learning which has become a leading pedagogical approach that is now being implemented worldwide (Rickinson et al., 2004) and recent Government calls for 'schools to make better use of the outdoor classroom as a context for teaching and learning',1 the Field Studies Council (FSC. The literature has shown that naturalistic EE programs that focus on scientific methodologies have helped students to acquire scientific knowledge, understand scientific concepts and gain a better understanding of the principles associated with the topic in question (Sauvé, 2005). This has been shown in learning about watersheds (Zimmerman & Weible, 2017), earth science (Brkich, 2014), and human health and welfare issues (Buxton, 2010). EE programs implemented according to the naturalistic approach helped students to develop their understanding of local ecosystem through direct experience (Keynan et al., 2014).

According to the naturalistic approach, the goals of EE are to provide students with skills enabling them to work towards ecological awareness, as well as towards biodiversity conservation as part of pro-environmental behavior (IUCN, 1970). Biodiversity conservation, as part of EE was adopted by many governments to translate the 1992 Convention on Biological Diversity into concrete measures and actions. The Convention obligates states to protect biodiversity by using policy instruments, media, research, and education (Dreyfus et al., 1999). The aim of EE programs is to help people understand and appreciate natural and cultural resources, while also developing skills and practices for explaining how to conserve those resources for future generations (Tilbury, 2011). There are several key EE concepts in the context of biodiversity conservation: conducting experiments, promoting outdoor learning through outdoor activities, coming in contact with live animals, and encouraging community engagement (IUCN, 1970).

### The Lesser Kestrel Population in Israel

This LK program was established in 1996 emphasizing social, educational, and environmental values. For more than two decades fifth grade students at Falcon School (pseudo name) have been helping to protect the local LK population, which nests in their school. Learning about the LK's life cycle while examining the interactions between the LK and its environment enable students to develop system thinking. The LK program consists of two weekly hours in which students meet as an extracurricular program integrated into the school's schedule. Many of the classes engage in outdoor learning, allowing students to observe the LKs in their yards. The students learn about the LK's lifecycle as well as a diverse range of topics, from human nature conflicts to the ongoing tensions between nature preservation and urban development. Students also develop skills such as teamwork, noting their reflections in writing, oral presentation, data collection, observation, and group discussion.

In this study, in addition to science classes that focused on the LK ecology, the students built more than 200 LK nest boxes, designed and implemented scientific experiments to determine the locations in which to position the boxes. The nest box building was part of a big question that opened the first learning session: What are the factors causing the decline in LK population and how can we minimize this decline? Community members helped in efforts to preserve the LK by hanging up nest boxes built by the children according to the students' survey and experiment results. As students performed surveys of the LK nests and provided assistance in monitoring the LK population, they developed their nature-observation skills, and engaged in data collection of both biotic and abiotic parameters. Furthermore, they created Excel databases into which they entered the information collected, and sent reports to the Israeli Birding Center.

One of the highlights of the program is "*Lesser Kestrel Day*," a ceremony held in late May when the young LKs first open their wings and prepare to leave the breeding colony at the schoolyard. As part of the event, fifth grade students guide over 1,200 visitors through the grounds and explain the plight of this endangered species. Guiding adults on LK Day provides the students with the opportunity to integrate their scientific skills with their knowledge and values. The students' skills include, peer teaching, guiding students from other schools, and guiding adults on LK Day. The students presented their knowledge about the LK ecological system, and emphasized the factors and relationships that influence its survival rate. By contemplating and discussing moral issues relating to animal protection such as the actions needed to cope with invader species such as the Myna bird, the students practiced forming values and attitudes towards biodiversity.

## METHODOLOGY

### Research Population

The study included 28 boys and 25 girls in fifth grade (n = 53) living in near the school area in Northern Israel. The students participated in the LK program over one school year.

### Research Approach

In this study, we collected extensive, in-depth data. Our strategy was first to 'zoom in' on individual students, gathering as much information as possible about each one of them, and then to 'zoom back out' – generalizing from this data to distinguish their system language and measuring up their outcomes (repertory grids). This methodology can provide important insights and knowledge, in this case about how students perceive the complexity of the LK ecology as a system.

The analysis based on the System Thinking Hierarchy (STH) model developed by Ben-Zvi Assaraf and Orion

(2005), which is a form of conceptual representation designed to provide learners with a coherent organizing framework for thinking about complex systems, which may assist them in model construction. This model divides system thinking into eight hierarchical characteristics, which are constructed in an ascending order of advancement into three sequential levels: (A) analyzing the system's components; (B) synthesizing the system's components; and (C) implementation. The eight characteristics are:

1. Identifying the system's components and processes (level A).
2. Identifying simple relationships among the system's components (level B).
3. Identifying dynamic relationships within the system (level B).
4. Organizing the system's components, their processes and their interactions within a framework of relationships (level B).
5. Identifying matter and energy cycles within the system (level B).
6. Recognizing hidden dimensions of the system (level C).
7. Making generalizations about the system and identifying patterns (level C).
8. Thinking temporally (level C).

As aforementioned, this study examined elementary school students' understanding of the LK's ecosystem. To achieve this, we characterized the students' perceptions according to their place within the STH framework before and after the learning process. Using the detailed STH framework assisted us in noticing subtle changes in the students' systems perception, thus providing us with some insight as to the development of their system understanding (Keynan et al., 2014).

## Research Tools and Analysis

Two research tools were employed in this study: the repertory grid technique, and the semi-structured interview.

## The Repertory Grid Technique

The changes in the students' perceptions of system complexity were tracked by means of repertory grids (RG), administered both before and immediately following the LK program. The RG technique is based on Kelly's Personal Constructs Psychology. This technique takes the form of a highly constructed interview, exploring personal constructs and given objects of discourse (Kelly, 1955). Although originally developed for the field of psychology, the RG technique is generally acknowledged as a reliable tool for representing teachers' ways of thinking (Rozenszajn & Yarden, 2015) including content knowledge (CK. This technique is used in educational research to explore learners' perceptions through the personal constructs they create. RG have also been used to track system understanding (Ben Zvi - Assaraf & Orion, 2010; Keynan et al., 2014; Snapir et al., 2017) trading as Taylor & Francis Group. Science education today has become increasingly focused on research into complex natural, social and technological systems. In this study, we examined the development of high-school biology students' systems understanding of the human body, in a three-year longitudinal study. The development of the students' system understanding was evaluated using the Components Mechanisms Phenomena (CMP. In the current study we have adopted the approach of Keynan et al. (2014) who utilized the RG approach to evaluate students' development of system understanding in outdoor learning as part of EE, as reflected in participants' position in this study through the STH framework.

The building blocks of the RG technique are called elements (the topics of study within the domain of the investigation), constructs (participants' ideas about these elements) and ratings (relations among elements and constructs as viewed by participants). Elements can be obtained in two ways the researcher: 1) supplies the elements to participants, who focus only on creating the constructs. 2) asks the participants to provide elements themselves (Latta & Swigger, 1992). In this study, the elements were provided by the students as a part of a semi-structured interview. Using this personal list of elements made it possible to compare the change in the way every individual student perceived and used each element over time, and to determine how the concepts which their biology teachers deemed most important were being employed by the students in their constructs.

The participants' analyses of the elements and the relationships between them are represented by constructs. There are different processes that elicit constructs. This study employed the most common method – the triadic elicitation process, in which participants are asked to randomly choose three elements and then explain to the interviewer some aspects in which two of the elements are similar to each other whereas the third is different. Construct elicitation is demonstrated by the examples of Students A13, B5, and C22 in the results section.

This triadic game process was repeated eight times for each participant. Throughout all eight cycles, the students were interviewed about the answers they provided – the interviewer asked questions to clarify the differences and similarities between the elements as these students perceived them. Thus, the researchers elicited the constructs from the students' explanations of similarities and differences, during the interview. This process generated eight constructs for each student, indicating his/her own mental model.

### Analysis of Repertory Grid Data

The constructs elicited were grouped into categories and sub-categories using the STH-model (Ben Zvi - Assaraf & Orion, 2010)during, immediately after, and 6 years after completing a year long systems-based learning program. The employed research tools included observations, semi-structured interviews, and a number of \"concept viewing\" tools (drawings, concept maps, and repertory grids as the organizing principle for categorization. The major categories are the three sequential levels of system thinking: (A) analysis, (B) synthesis, and (C) implementation. The subcategories refer to the eight characteristics of system thinking described in the literature review. In order to examine the influence of participation in the program on the development of students' system thinking abilities, the distribution of the number of students who demonstrated each of the three STH-levels was calculated, for the pre- and post-test results (Figure 1).

We used the McNemar test to establish if there were variances on a dichotomous dependent variable between two related groups, while testing consistency in responses across two variables. This test uses analysis of pre- and post-test study designs. The McNemar test is commonly employed in analysing matched pairs, which is the case in this study. The test is a non-parametric test for repeated testing of nominal variables. To obtain deeper insight we also calculated the number of students who expressed the different constructs included within each of the three STH-levels. For validity purposes, analysis of the RG data and categorization according to the STH-levels was conducted separately by the researchers, and the results were compared and discussed until agreement was reached regarding the constructs, construct categories and sub-categories.

### Semi-Structured Interview

The purpose of the semi-structured interview is to reach a better understanding of participants' experiences and of the meaning they make of that experience (Galletta, 2013). Semi-structured interviews are usually associated with qualitative research methods (Seidman, 2013). A semi-structured interview is a tool by which the researcher collects the necessary information by direct questioning, usually in a face-to-face conversation. The semi-structured interview consists of a structured set of questions designed to guide the interview in a focused manner, together with the flexibility created by the dynamics that emerge from the interaction with the interviewee (Fossey et al., 2002). A semi-structured interview is carefully planned and provides a repertoire of possibilities based on a protocol (Lodico et al., 2010). The questions are designed to be sufficiently open as to enable the researcher to explore new ideas that come to mind during the conversation, while at the same time keeping in mind the relevant theories and the research purpose (Wengraf, 2001).

### Analysis of Semi-Structured Interview Data

Thematic analysis is a qualitative analysis method that enables the researcher to identify emergent themes and apply deep analysis of the data. This process is practiced by reading the data several times while taking notes of important points of interest and thus creating a preliminary set of codes as well as themes and sub-themes. These sets of data are then read again to ensure that the researcher does not overlook important codes. A thematic analysis as this, serves as a flexible and beneficial research tool that can providedeep , specified , yet complex data (Braun & Clarke, 2006).

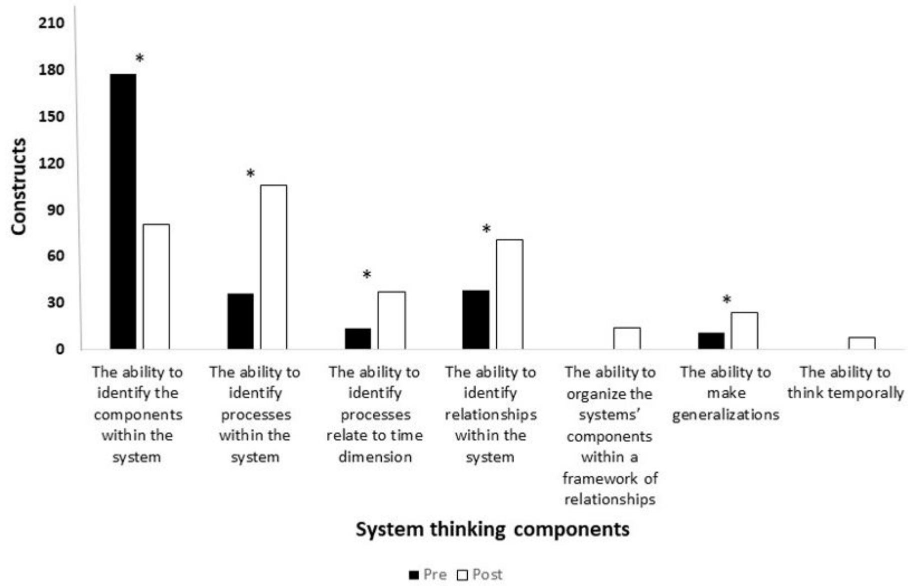
## RESULTS

Results are presented from two perspectives: First, the RG data obtained from the whole sample of 53 students was analyzed using the STH-model. This perspective was used to elicit a general picture of the development of system thinking skills as a result of participation in the LK program. Second, for each level of system thinking, students impressions and perceptions of their learning experience were added, derived from the semi-structured interviews. Results from the RG were converted into constructs (n = 800) by coding the students' interpretive statements for each chosen element. Next, all the constructs were sorted into categories using a content-analysis procedure. Lastly, semi-structured interview categories were combined according to the research questions.

The students created 800 structures, of which 182 pertained to emotional and cognitive aspects relating to outdoor learning. Some of the emotional aspects related to involvement in the learning process. In this article we will present an analysis of 618 structures, 277 from the beginning of the learning process and 341 from the end of the learning process, related to aspects of the LK ecosystem. Due to the limited scope of this paper we cannot include all the structures. Therefore, we will generally refer to aspects related to students' engagement in the learning process through a few citations.

The results are organized according the research questions, which also reflect the levels of the STH thinking

Figure 1. Distribution of the number of students' constructs at the beginning of the program regarding ways of helping to protect the LK, and following the end of the EE program (*p < 0.005)




model. Figure 1, presents the number constructs for each of the three major STH-levels, prior to and following participation in the program. In the pre-test, while the majority (98%) of students demonstrated the analysis-level, 54.7% demonstrated the more advanced synthesis level and 20.8% demonstrated the most advanced implementation level. This suggests that the students entered the learning process with both affective and cognitive readiness to discuss the subject of ecosystems and were familiar with the concept, which also provided them with a solid foundations for enhanced development of a more complex systemic understanding of their local ecosystem as the program progressed. In the post-test, expression of the analysis level decreased (79%) while demonstration of the two more advanced levels increased. Most significantly, after participating in the program, 80% of the students demonstrated the synthesis level, and 45.3% demonstrated the implementation level.

The post-test results indicate that these students developed a significantly more complex view of the LK ecosystem: they demonstrated the ability to generalize some of the ecological phenomena, such as the temporal impact of migration, and human interferences with the ecosystem such as agriculture and the distribution of an invasive species. These cognitive tools may enable them to better cope with complex, biodiversity-related environmental issues in their local environment. The constructs created by the students within each of the three STH levels prior to and following participation in the LK program were also compared (Figure 1).

In order to address the question "*In what way do students' perceptions of complexity change as a result of their participation in the LK program?*" We examined and presented the complexity according to the study's three sub-questions.

### (1) What are the Students' Abilities in Identifying the Components and Processes that Exist in the LK Ecosystem?

The data pertaining to the analysis level (Table 1) point to a number of findings:

The 178 constructs created by the students were related to components while only 36 constructs referred to processes. In the end of the learning program, 10 constructs were attributed to processes. As a result, in the post-test the majority of students (94%) used a process-based explanation in comparison to the pre-test (58.5%). For example:

Student A13 pre-test: "*Male and female, claws, nesting boxes - nesting boxes is the exception, it cannot be associated because the male is more beautiful than the female. The male may also be a LK and have bigger claws than the female*". Construct - difference between male and female

Student A13 post-test: "*Nesting boxes, mating, observation - observation and mating are associated. We observe what they do and sometimes it can be mating, nesting boxes is the exception because they do not mate in nesting boxes*". » Construct- LK mating

Constructs that represent elementary processes such as "*the LK's predators*" decreased very significantly between the pre- and post-test. On the other hand,

Table 1. STH level "analysis of system components"

| Examples of Constructs | Quotes |
|---|---|
| *(1) The ability to identify the components of a system* | |
| Differences between females and males; | Not all LK's are red, the female is bigger than the male, the LK is a bird of prey |
| Nest sites of the LK | Fish ponds are the exception, because nesting boxes and LKs are related to each other; Nesting boxes are a place where LKs can nest. |
| The nest box characteristics | Experimentations related to the nest boxes because we want to know why the nesting boxes are placed in the north and not in the south. I think the temperatures should be lower in the north. |
| Biotic and a-biotic | *Ceryle rudis* and *Motacilla alba* are animals; a biotic factor is something alive; biotic is not only animals, it is also bushes and trees, for example. |
| Claws as characteristics of birds | The LK has claws, and with them he catches prey. The claw is sharp and curved, and with it the bird picks up and catches its prey until it brings it the nest; I saw caterpillars and insects and once I saw a mouse. |
| The LK's natural enemy | The owl is exceptional because it is the enemy of the LK; Pelican and *Ceryle rudis* have a common characteristic – both of them do not attack the LK. |
| *(2) The ability to identify processes within the system* | |
| Pellet process | The falcons lay the eggs inside the nest. When the chicks hatch they are naked, they do not have feathers. As they begin to grow they also grow feathers. |
| Incubation and fledgling development | Chicks are the exception, because in the nest boxes they lay eggs incubated and chicks live and develop in the nesting box. |
| The LKs predators | We watch the *Ceryle rudis* catching its prey: *Ceryle rudis* is the exception as the owl is the predator of the LK…It preys on the chicks… Owls and LKs are associated with each other. |
| Associated to the mating of the LK | The male and female are associated with each other because he mates with her and then she lays eggs that become chicks. |
| Associated to pellet vomiting | LK and pellets are associated: Pellets are part of the LK's life, it's like we must go to the toilet … Every time after he eats everything and cannot swallow, he vomits. |
| *(3) The ability to identify processes that relate to the time dimension* | |
| Migration | The LK migrate when they fly to Africa: The owl is the exception because it is not associated with the migration of the LK. The owls do not migrate. |
| Being a fledgling is a development stage of the LK | They grow to be fledglings… The fledgling stage is part of the life cycle. The life cycle takes place in Israel. |
| In the past the LK nested in nature, in the rock niches | A niche in the rock is the exception because it helps the LK and gives them a place to nest. Once they used to nest in it before the open spaces were finished. Naturally they are supposed to nest in rock niches, but this does not happen anymore. |

constructs reflecting complex phenomena were present only in the post-test. For example:

Student B5 pre-test: "*LK, nesting, cameras in nesting boxes - The LK and nesting are associated because it nests in the nest box, the falcon incubates the eggs and take care of the young chicks.*" » Construct – LK Nesting

Student B5 post-test: "*Nesting boxes, LK, Myna - Mynas are an invasive species and it captured the LK's nesting boxes which we built for the LK. The Mynas are not a natural species in Israel. I do not know where the Mynas came from. Someone brought the Mynas from abroad… they became invaders... The Mynas capture the LK's nesting boxes*". Construct - Effect of the predominance of the Mynas on the nesting boxes

Interestingly, constructs referring to a sequence of actions were mentioned by 56.6% of the students in the post-test, in comparison to 24.5% in the pre-test. The number of constructs referring to processes that relate to the time dimension were significantly increased following the learning process (McNemar's test, $p = 0.001$). The construct "*migration*" refers to the ability to identify processes that take place in time dimension, for example: “*The owl is exceptional… it is not associated with the LK’s migration. The owl does not migrate… the LK cannot survive in Africa in the winter so they migrate*”. In the end of the learning process most of the students related migration to nesting as part of the LK’s life cycle. For example, “*Because most of the nesting takes place in the [Israeli] area, they migrate from Africa to Israel. That’s their life cycle and what they do every year is breed and raise chicks*”.

It is important to note that the students’ most elaborate and detailed explanations were related to outdoor activities in which they participated during the learning. The students monitored the ecosystem by watching and observing the LK’s natural behavior in the schoolyard. The students emphasized the importance of learning outdoors, as one explained, “*It’s easier to understand nature when you learn outside… more than when you read a book… to be out of the class makes it tangible*”. Learning outdoors included observation activities, which explicitly emphasized the biotic and abiotic characteristics of the ecosystem, and characteristics such as LK nests inside the school roofs, and the fledglings. This point emphasizes the importance of outdoor learning, which helped the students to identify the components of the system at hand, as one of the students emphasized, “*We used the binoculars, and then we went to the schoolyard to observe birds. We identified the birds’ characteristics… beaks, legs, and nests*”. Other explained how “*the binoculars helped us see the details better…we looked at the yard’s components…trees, birds…we could identify the birds according to their color, size, songs, male and female feathers*”. To summarize, outdoor learning helped students to recognize the ecosystem components, comprising part of the STH analysis-level.

### (2) What are the Students’ Abilities in Identifying Interrelations within the LK Ecosystem?

Findings from the RG indicate that the interaction which refers to the effect of one component on another accounts for most of the students’ responses in the synthesis-level in the post-test (n (pre) = 38, n(post) = 71, McNemar’s test, $p = 0.015$). First, the two dominant constructs in both the pre-test and the post-test related to the bird structure and to its food. Second, in the post-test the students presented the human activity influence on the LKs’ survival or, alternatively, extinction, due to construction and agriculture (Table 2). Third, 14 of the 71 constructs were present only in the post-test, and they reflect the students’ ability to create a web of relationships, which is a more advanced understanding of systems within the synthesis level. In the post-test, 79% of students had the ability to recognize interrelationships in the system. Only 26% of students referred to phenomena connected to a multiple cause and effect interaction: An explanation described the LK’s life cycle. Table 2 presents a rare example of this construct.

Interestingly, the students’ activity in helping to protect the LK encouraged them to think on the synthesis level of the STH. During the semi-structured interviews the students mentioned several activities that promoted their pro-environmental behaviors, such as the experience of building the nest boxes. As one of the students stated, “*The LK is in danger of extinction. This means there aren’t many of them. Our job is to protect them and we have built nest boxes for them*”. From this quote, we learn that nesting boxes helped students to understand the concept of extinction. The students’ involvement in building the nest boxes led them to understand their importance in protecting the LK. The students understood that “*coloring the nest boxes white reduces the temperature inside them*”. In this way, the students created a language of relationships in the ecosystem. Another example which the students mentioned was the survey aimed to identify places in which to locate the nest boxes in the local community. For example, one of the students explained how they “*checked if it was possible to locate the nest box at the north side of the house to avoid heat damage to the eggs and chicks*”. Another student stressed the need to check several criteria for locating the nest boxes, such as “*are there domestic pets in the yard, or if the family is willing to hang nest boxes in their yard*”. The students’ decision where to locate the nest boxes according to their survey was an important activity which expanded their understanding of the LK survival chances in a hands-on way.

These activities demonstrate practice and training which provided students with the opportunity to think about the relationships between the components of the ecosystem as part of the STH synthesis level. The students described the influence of human activity on the survival or extinction of the LK and their own activism, which helped to save the LK population. This understanding helped students to be engaged in the learning process. Moreover, the hands-on experience helped them to acquire the ability to organize the systems’ components and their interactions within a framework of relationships.

### (3) What Are the Students’ Abilities in Identifying Both Patterns in the System, as well as the Time Dimensions of the LK Ecosystem?

On the implementation level, all the constructs except for one appear only in the post-test. These constructs reflect the idea that the LK is an endangered species. A representative explanation leading to this construct

Table 2. STH level "synthesis of system components"

| **Examples of Constructs** | **Quotes** |
|---|---|
| *(4) The ability to identify relationships between the system's components* | |
| Nest box characteristics influence LK's survival rate | A 5 cm hole so that only the LK can get in, a balcony so that the chicks do not fall out, ventilation holes to make it less hot inside the box. |
| Relationship between the bird's construct and its food | Each species of birds has a special beak according to its needs. The pelican needs a large and thick beak because it eats fish. The LK has a small beak which is curved and sharp, for cutting meat and eating it. |
| Invasive species build nests in the LK's nesting boxes | Mynas affect the LKs most. Mynas took over the LKs nest boxes. We also saw the Mynas' chicks and eggs. The Mynas go into the boxes to catch the LK nest box. |
| Associated to the reduction in nesting sites due to construction | Since cities are expanding, the LK's natural habitat and nesting areas are shrinking and the birds have less places in which to eat and nest. |
| Birds hunt at certain hours to find food | There are birds that hunt at night, like owls; there are those that hunt during the day, and those that hunt in the evening. The birds should hunt at the right time because the prey also leaves at certain hours and at other times it burrows or is found in areas where it is hard to hunt. |
| Associated with the place where it is easy for the LK to find food | It is easier for the LK to catch their food in the low vegetation and not inside the old roofs. Open spaces are areas which allow them to find food like insects – which helps the LK |
| *(5) The ability to organize the systems' components and interactions within a framework of relationships* | |
| LK's life cycle | The best month in the year for the falcon is May because that is when it is interesting to see how they grow, hatch, catch the food and bring it to their chicks, and how they feed them. Because most of the nesting takes place in the area, they migrate from Africa to Israel. This is their life cycle and what they do every year: breed and raise chicks. |

appears in Table 3. Furthermore, most of these constructs point to an improvement in students' ability to generalize regarding the ecosystem (McNemar's test, $p = 0.015$). Interestingly, students who demonstrated understanding of processes occurring in time dimension such as migration were also the students who developed the ability to think temporally, and related time to seasonal changes. Here are a few examples of students' responses:

Student C22 pre-test: "*Hunting hours, birds, birds' defense - Shared: birds and hunting hours. There are birds that hunt at night like owls, others hunt in the daytime and others in the evening, The birds should hunt at the right time because the prey also leaves at certain hours and at other times it burrows or is found in areas where it's hard to hunt*". Construct - Birds hunt at certain hours

Student C22 post-test: "*Old roof, pellets, bird wintering - old roof is the exception because pellets and wintering are related to things that the LK does and part of its life cycle. The LK are in Israel for the winter and in Europe from February to June. In late June they start flying back to Africa. When they arrive at the breeding areas, first the males arrive. Only in March they begin to approach the nesting boxes. The courtship is in April and then the birds capture the nesting boxes and lay their eggs*". Construct – wintering as part of the LK's life cycle

It is important to note that the students' performance as guides on the LK Day required generalization of their understanding about the LK as part of the ecosystem by practicing and expressing their knowledge. The students presented their own values in the context of conflicts, such as the moral question regarding the Myna's damage to the LK. For example, one of the students claimed that when guiding "*we should not interrupt the natural process… we should let the LK solve the problem [with the Mynas]*". On the other hand, other students argued that "*the Myna is an invader species and we should help the LK to eliminate the Myna*". This example demonstrates students' critical thinking processes and the dialogue between them. This dialogue forced students to take a stand and to debate their opinions regarding complex relationships such as the diverse influences on the survival of the LK. They could not have engaged in this dialogue had they not understood the system's complexity. The dialogue thus demonstrated their ability to generalize their understanding on the system level.

Furthermore, the students convinced the adults who took part in the LK Day to help them protect the LK and contribute to the solution of a real-life problem. As one

Table 3. STH level "Implementation"

| Examples of Constructs | Quotes |
|---|---|
| *(6) The ability to make generalizations* | |
| The LK is an endangered species | The falcon is a rare bird that has been saved from extinction. It is an endangered species… This is important because they are in danger of extinction. We want them not to be exterminated so that they stay in Israel, so we build the nest boxes . |
| *(7) The ability to think temporally: retrospection and prediction* | |
| Migration as part of the LK's lifecycle | In the winter (January) the falcons arrive in the breeding areas. Nesting in Israel is part of their life cycle. |
| The nesting season and winter season as part of the LK's life cycle | Wintering is part of the LK's life cycle. They winter from late June to January and then migrate to Asia and Europe. The reason for migration is that in the winter there is not much food, and if they move to another country their chances of finding food and surviving are greater. |

student pointed out, "*On LK Day people came from afar... they believe in us that we can influence the situation and bring about change*". This quote illustrates students' understanding of the meaning and influence of their actions, and strengthens their sense of self-efficacy. They acknowledged their power to convince adults to protect the LK. Consequently, the guiding experience helped students to be engaged and understand the importance of protecting the LK, as one student noted: "*People were interested…Because we worked on this all year long, we could explain to many people about the extinction of the LK*". This demonstrates the activism that enabled the students to explain to others what they themselves learned and internalized, which in turn might contribute to engagement in the learning process and to heightening the level of their STH implementation. Appendix 1 provides examples of the characteristics of the LK educational program in the context of system thinking level.

## DISCUSSION

### Change in Students' Perceptions of Complexity Following Participation in LK Program

The present study investigated whether and to what extent, system thinking perceptions could be conveyed to elementary school students. The STH multilayered model was implemented as an inquiry-based curriculum focusing on ornithology in the local natural environment as part of science education. In our study, the teacher included meta-cognitive interventions and instructional approaches to develop system thinking. Such explicit instruction, where meta-cognitive knowledge and skills are explicitly taught or explained to students, was found in the literature with regard to meta-cognition development (Zohar & Barzilai, 2013). The data indicated that despite the fragmented and partial perception of the LK's ecosystem, most of the students made significant progress in their ability to recognize interconnections among the components of a given system. Some students even achieved higher system thinking abilities, such as generalization. There is evidence that system thinking is viable with young learners (Ben-Zvi - Assaraf & Orion, 2010)during, immediately after, and 6 years after completing a year long systems-based learning program. The employed research tools included observations, semi-structured interviews, and a number of \"concept viewing\" tools (drawings, concept maps, and repertory grids, but insights on its role, purpose, and function with younger elementary grade students are relatively scarce.

Analysis of the students' constructs through the lens of STH provides insight regarding the conceptual understanding of systems, which they brought into and attained from the learning process. The constructs created by students within each of the three STH levels preceding and following participation in the program represent the students' mental model of a system, allowing us to take note of the slight changes in their system perception over a period of time. Comparing the distribution of the constructs among the three STH levels preceding and following participation in the program demonstrates the transition which the students underwent in the process of advancing on to higher levels of system thinking skills: following the learning experience most students expressed some aspects of temporal thinking in processes, interactions and predictions. The LK program enabled the students to study with scientists in a natural outdoor environment, while addressing the dimensions of time and space required for the development of ecosystem understanding. Although, it was difficult for the students to develop an understanding of processes in time dimension, the outdoor environment, which included observation of the LK's ecosystem, enabled students to develop their comprehension of processes in time dimension.

Although most of the students recognized processes in time dimension, such as changes in the LK's ecosystem that occur over time, and the dynamics of the migration phenomenon, less than a third of the students presented temporal thinking. Temporal thinking is the ability to look forward in time and predict expected results of a multitude of earlier interactions. Studies have indicated that temporal thinking is one of the aspects of system thinking which is especially challenging even for junior high school students (Ben Zvi - Assaraf & Orion, 2005; Magntorn & Gustav F Helldén, 2006; Sweeney & Sterman, 2007)which were implemented in order to collect the data concerning the students' knowledge and understanding before, during, and following the learning process. The findings indicated that the development of system thinking in the context of the earth systems consists of several sequential stages arranged in a hierarchical structure. The cognitive skills that are developed in each stage serve as the basis for the development of the next higher-order thinking skills. The research showed that in spite of the minimal initial system thinking abilities of the students most of them made some meaningful progress in their system thinking skills, and a third of them reached the highest level of system thinking in the context of the hydro cycle. Two main factors were found to be the source of the differential progress of the students: (a. This mental acquisition of complex accumulation processes requires broad cognitive abilities, and therefore it is not surprising that students encounter major difficulties in perceiving systems. Processes in the time dimension are not common components in the STH model literature. We believe that developing the understanding of processes in the time dimensions is important as a preliminary stage for developing retrospective thinking. Therefore, in accordance with our findings we suggest that processes in the time dimension be included in the analysis level.

As was found in our study, complex accumulation processes can be demonstrated by explaining ecological phenomena, when students must coordinate one or more entity-behavior relationships with various properties of those relationships and how they might aggregate over time to explain what Vattam et al. (2011) have termed the function of the system, or the system-level outcomes. For example, the LK's ecosystem includes system-level properties such as the amount of food and the number of LKs. These properties cycle back and affect the entity-behavior relationships: when additional LKs eat the food the total amount of food available decreases; part of the population dies, and consequently the number of LKs decreases. This cycle may be visualized as a series of snapshots of system-states that describe the properties of the system at any given moment (Vattam et al., 2011). Engaging in mechanistic reasoning about these types of phenomena involves coordinating entity-behavior relationships or properties with system-states into a chain-like sequence of events, connecting several interactions together over space or time (Krist et al., 2019). Mechanistic reasoning is an intersecting form of thinking across multiple scientific practices. As a heuristic, it can help students guide decision-making, evaluation, and reflection as they construct and test scientific ideas. When students use these heuristics they do so in a way that requires them to develop and use mental models, especially when recognized relationships across space and time (Krist et al., 2019), as presented in our study of learning about the LK ecosystem.

Furthermore, Chi and colleagues (Chi et al., 2012)or how ink dropped into water appears to \"flow\" argue that students' difficulties in understanding complex causality and nonlinear dynamics present major challenges. Their claim is that students have a tendency to comprehend and deduce by using direct-causal schema, in which they accredit behaviors and results to immediate one-to-one interactions, rather than deducing with an emergent schema that recognizes that the interconnected and network-like nature of systems will generate non-linear effects. The non-linear effects are not the only concept, which is difficult to understand; as Grotzer and Basca (2003) have revealed, students also often reason about immediate effects rather than cascading or indirect effects. They fail to realize that a change in one population can have impacts on populations that are not directly linked to it, through domino-like or cyclic complex causal relationships. These complexities understanding were also evident in our study.

Perceiving systems, as suggested by Gilissen et al. (Gilissen et al., 2019), requires current secondary biology education to address the investigation of the universal characteristics of biological systems by students: identification of the system, inputs and outputs, emergent properties, and the development of systems over time. Biologists study living organisms varying from cells and plants to human behavior and ecosystems. To understand how these organisms function, biologists constantly analyze different levels of biological organization, moving back and forth between them, i.e. from the molecular to the ecosystem level and back (Gilissen et al., 2019; Knippels & Waarlo, 2018). Although, biologists who are used to thinking within and between these levels of organization are able to identify patterns, and then to transfer their insights to other contexts, for the lay person, such as students in high school this is very challenging (Knippels & Waarlo, 2018). It is even more challenging for elementary school students, as in the case of the study presented in this article.

Another system thinking skill which is difficult even for junior high school students to master is the ability for generalization. In this study, participation in the LK program led to the development of some of the students' ability to generalize. Nevertheless, the only pattern that was recognized by the students was "*The LK is an endangered species*". Similarly, Keynan et al., (2014) pointed to students' difficulties in generalizing, when the ability they developed was restricted to the desert environment while transfer of concepts and processes from the desert system to a broader ecological context was not evident.

### The Characteristics of the Unique Learning Environment Reflected by Elementary School Students' Explanations of Phenomena Related to Bird Ecology

As aforementioned, findings suggest that fifth grade students developed system thinking on various levels. According to the findings, three educational activities in the unique learning environment described here encouraged the development of system thinking: (1) Outdoor learning (analysis of system component through the lens of outdoor learning). (2) Authentic learning through pro-environmental behavior (synthesis of system components through the lens of activism and pro-environmental behavior). (3) Students serving as teachers for their peers, other students, and adults (implementation through the lens of students as teachers). These activities, were interrelated and engaged students in the learning process.

### Analysis of System Components through the Lens of Outdoor Learning

Outdoor learning enhanced the understanding of processes that relate to the analysis of system components. As part of the outdoor learning, the teacher demonstrated how to activate and apply meta-cognitive knowledge and skills during instruction or performing a task, which was defined in the literature as meta-cognitive modeling (Zohar & Barzilai, 2013). The outdoor learning included long-term observations in the same place, and enabled the monitoring of the LK in the nesting colony located in the schoolyard. This enabled students to identify processes in the system and processes that related to the time dimension. The students took notice of the five-month period (in the beginning of the year) without the LK. Later on, the students observed the LKs' arrival and their behavior. This phenomenon created curiosity and expectation through continued observation of the birds in the surrounding ecosystem, which enhanced their engagement in the learning process. Observing the arrival of the LK and its behavior created a concrete interaction with the components of the ecological system related to the LK.

The value of the concrete interaction was also revealed and described by Ben-Zvi - Assaraf and Orion (2005), who suggested that concrete interaction with the components of water cycle (such as the ecosystem in our study) created an actual basis on which students were able to develop a more abstract mental model of the interrelationships within and among the systems. The current study joins a series of previous studies which highlight the potential of an outdoor learning environment (DeWitt & Osborne, 2007; Dillon et al., 2006)school trips to these places are not often conducted in a manner that could maximise learning. In addressing this issue, a Framework for Museum Practice (FMP . When properly conceived, adequately planned, well taught and effectively followed up, it may serve as a cognitive bridge to overcoming cognitive barriers to the development of high-order learning skills (Orion, 2007).

Orion (Orion, 1993) suggested that the main role of using the outdoor learning environment in the learning process is to directly experience concrete phenomena and materials as they appear in the real world. When relating to young students whose abstract thinking abilities are still somewhat undeveloped, this point becomes even more crucial. Our study provides a positive answer to the question of whether such thinking can be promoted even by elementary school students, by indicating that with suitable teaching methods students are able to promote their system thinking in the context of the water cycle,. Moreover, from the educational constructivist perspective, outdoor learning focused on birds is an active process whereby learners derive information from the environment and construct personal interpretations and meanings based on prior knowledge and experience. Tracking birds requires developing skills, which students rarely use at present time. Moreover, it requires the ability to observe details, focus on one thing, and employ peace of mind, which have mostly disappeared from the lives of students in the wake of the digital environment in which they live. Birding may develop interpersonal communication and information-sharing skills as a result of collecting information and analyzing data. Studies have shown that learning programs devoted to the preservation of bird biodiversity can be effective, and that exposure to birds increased students' knowledge, improved their attitudes toward birds, and even increased their willingness to act for raising awareness to these birds in their community (Chen & Cowie, 2013; Zion et al., 2011). Our findings concurred with these studies, showing that learning about and protecting the LK increased students' system thinking and improved their pro-environmental behavior.

Contrary to our findings, In other studies (e.g. Trumbull et al., 2005)called Classroom FeederWatch (CFW found no difference in students' knowledge and understanding of scientific inquiry after engaging in the observation of birds. They suggested that this was because the educators and ornithology experts who had designed the activity did not foresee the amount of 'scaffolding' that the students would require to support their engagement in systematic observation of birds in complex ecosystems. Their findings correspond to those of other researchers who studied how children engage in observation in other contexts, such as astronomy (Kameza & Konstantinos, 2006) and plant life (Johnson & Tunnicliffe, 2000). In our study, the educational program consisted of a year-long learning process and included improving bird-watching skills in both the concrete and abstract dimensions. Real-time observation of long-term processes including migration, the LK life cycle, and comparison between the size of its population in the past and in the present, enabled students to identify processes that related to the time dimension. Although, the students could not follow the LKs' migration in real time, the expectation for the LKs' arrival emphasized the understanding that the LK is located in a different ecosystem.

The learning that included examining the size of LK population in the present compared to the past developed the students' ability to think temporally about processes that have reduced the size of the population throughout the years. In this way, the students' ability to identify process in the time dimension developed not only regarding concrete phenomenon, but also in comparison to the past and to long-term processes. Fifteen percent of the students had the ability to think temporally in retrospect, as well as predictively – which reflects the implementation level according to the STH model. According to the literature, it would seem, then that children must undergo a transition from a state of everyday watching to a state of significant scientific observation. Eberbach and Crowley claim that allowing students to engage in scientific observation means not only expanding their content knowledge, but also providing them with proper tools and a supportive learning environment. Students need support, educational scaffolding and explicit guidance if they are to properly engage in scientific observation (Eberbach & Crowley, 2009). In this study, it seems that students were engaged in scientific observation of the LK population on both concrete and abstract processes, which enabled some of them to identify process that related to the time dimension.

### Synthesis of System Components through the Lens of Activism and Pro-Environmental Behavior

According to our findings, we can assume that pro-environmental behavior contributed to system thinking development, especially on the synthesis level, in the ability to recognize relationships within the ecosystem. For example, the physical experience of building nest boxes enabled students to understand relationships within the system through hands-on activities, which demonstrate the relations between abiotic factors (the nest box's characteristics) and biotic factors (LK survival). In other words, the students' pro-environmental behavior contributed to the understanding of the chain process, which means that factor A (e.g. the temperature) influences factor B (e.g. nest boxes' location) which influence factor C (e.g. LK survival). This finding fits in with the experiential learning theory, especially when integrating the physical aspect of the experience. In this way the students are able to realize the connections between theory and real life phenomena (Gorghiu & Santi, 2016; Kolb, 1984) – as in our study, where the physical action of building the nest boxes enabled the students to present their understanding on the synthesis level of system thinking.

Another example of pro-environmental behavior which contributed to system thinking development is the survey held by students to find the suitable places for locating the LK nest boxes in the area surrounding the school. The request to investigate diverse criteria in each potential site locating nest boxes enabled the students to connect several factors and weigh their characteristics regarding the possible location of the nest boxes, which in turn influences the LKs' survival. The teacher used graphic organizers as visual representations to help students organize their thinking, which according to the literature helps to develop meta-cognition in science learning (Zohar & Barzilai, 2013). In the nest location survey example, as in the example about the nest box building, students needed to implement theoretical ideas into practical solutions, a process discussed in the literature as developing system thinking (Dimante et al., 2016; Gorghiu & Santi, 2016). However, in this example students needed to consider not only one criterion as described above, but rather several criteria, all of which combine to form a prerequisite for locating the nest boxes properly. The learners were active partners in deciding on topics for study as well as in initiating, designing and conducting environmental activities in the local community on issues they learned through experience during the program. All this contributed to the development of system thinking.

The relations between pro-environmental behavior and system thinking discussed in the literature demonstrate that system thinking contributed to pro-environmental behavior (Dimante et al., 2016). In our case, the LK nest placing survey, as discussed in the literature, contributed to finding the best possible solution (Krogh & Jolly, 2012) for the declining LK population. This pro-environmental activity increased the students' interest and contributed to constructing their knowledge. Consequently, we suggest that pro-environmental behavior contributes to understanding the synthesis level of the STH model.

### Implementation through the Lens of Students as Teachers

Students' preparations to serve as guides on the LK Day influenced their system thinking in the following ways:

(a) It created an opportunity to organize the knowledge and meta-cognitive thinking, as meta-cognition is often regarded as a useful tool for enabling students to learn how to learn (Zohar & Barzilai, 2013). It is known from the literature that teaching a subject requires deep meta-cognitive understanding, as well as integration of knowledge (Nie et al., 2019). In this study, students were involved in peer teaching and community guiding. The students learned through this experience both from explaining what they had understood, and from learning from each other and from the community. The need to organize the knowledge and to explain it to others develops knowledge-generalization skills (Boud, 2001) and system thinking. In our study the fifth grade students experienced peer teaching and adult teaching, which enhanced their level of understanding and their ability to synthesize and integrate their knowledge. This is in line with the literature that investigated peer teaching and recognized the students' mastery of knowledge as a result (Cortright et al., 2005). Findings of this study suggest that the students' guiding experience required understanding the need to explain about endangered species in diverse ways, and encouraged the audience to adopt pro-environmental behavior. Thanks to this activity, several students reached the level of implementation as well as the ability to generalize their understanding. By the end of the process, 15% of the students attained the ability to think temporally according to the STH model. We can assume that this high-level thinking developed due to the guiding process, among other things.

(b) It facilitated the students' understanding of the LKs' ecosystem as a whole.

(c) It developed the students' engagement in the learning process and empowered them, giving them a sense of doing something significant in the real world. This gave rise to positive emotions towards the learning process. The emotional engagement in the learning process is important since it increases motivation to further study and understand complex issues (Krogh & Jolly, 2012; Sansone & Thoman, 2005), such as the global extinction trend of the LKs and the components of the ecosystem. An important component of peer and community teaching is self-efficacy (Bandura, 2006). This psychological construct represents the perception of one's ability to influence a situation through personal behavior. In the present study, the students emphasized their influence on the community through guiding, which increased their self-efficacy and helped to create responsible environmental behavior. Such behavior is more likely to be applied by individuals who believe that their actions have consequences for the environment (Smith-sebasto, 1995). A person with self-efficacy regarding the promotion of pro-environmental behavior is expected to be more likely to participate in specific activities aimed at the goal of ameliorating the environmental situation. Participating in the program was found to increase students' self-efficacy.

## CONCLUSIONS, LIMITATIONS, AND RECOMMENDATIONS

The development of system thinking may be complicated even for adults and higher education students. Therefore it is not surprising that it may be challenging for fifth graders. Despite the challenge, several students in this study developed system thinking in both the synthesis and implementation levels of the STH model. Most students reached the analysis level of the STH model. According to this study, it seems that the unique EE program, which focused on the LKs' survival in the outdoor setting facilitated the increase in the level of system thinking in elementary school students. The study's contribution to the field is in the understanding that meaningful and authentic outdoor learning which emphasizes pro-environmental behavior enables students to function as teachers, which creates a high level of engagement in the learning process. This leads to system thinking understanding in higher levels.

Moreover, the study contributed to the understating that elementary school students have the ability to identify processes related to the time dimension in the analysis of system components level in the STH model. The outdoor learning environment enhanced the development of this understanding, and this contributed to the development of complex thinking. We suggest that in the learning process there is a need to emphasize the ability to identify processes related to the time dimension, both through outdoor learning and through constant observation.

Despite the advantages of the program investigated in this study, its main limitation is the lack of a control group. This limitation raises the question of whether the LK program is what brought about the change in the results of the statistical tests. There is a wide variety of factors that may explain the results of this study, such as children's cognitive development, which occurs normally during fifth grade, watching nature films, or other factors.

We suggest that adding another category to the analysis level of "*Processes in the time dimension*" will allow us to trace students' conceptualization of the system's temporal aspect throughout the learning process. Consequently, more research is needed to establish appropriate assessment instruments in order to provide sufficient information about the development of the temporal dimension of system thinking.

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**Appendix A.** The LK program characteristics and system thinking level

| Discussion Components | Level of thinking | System thinking component | Examples from the program | Specific detailed examples from the program |
|---|---|---|---|---|
| Experiential learning of specific real world problems / Pro-environmental behavior – meaningful activity | Synthesis of system components | The ability to identify relationships within the system | • Building nest boxes<br>• Survey to identify places in which to locate the nest boxes in the local community surrounding the school | • Identifying the specific characteristics of the nest box (e.g. size, color, structure)<br>• Democratic class decision regarding location of nest boxes according to students' survey.<br>• Taking care of chicks that fell from their nest |
| Outdoor learning | Analysis of system components | The ability to identify processes within the system | • Observation<br>• Abiotic data collection for identifying suitable places to locate nest boxes | • Pellet analysis<br>• Feather analysis<br>• Observations of LK behavior<br>• Features of birds of prey<br>• Use of bird field-guide book<br>• Research of abiotic parameters in school yard |
| | | The ability to identify processes related to the time dimension | • Observation | • Using binoculars<br>• Outdoor activities to learn about the environment<br>• Bird migration observation<br>• Small camera in the nest box to follow birds' behavior in real time<br>• Observing the LK's life cycle |
| | Synthesis of system components | The ability to identify relationships between the system's components | | |
| Students as Teachers | Synthesis of system components | The ability to organize the system's components within the framework of relationship | • Students teach peers<br>• Students teach students from other schools<br>• Students teach college students<br>• Students teach adults on the LK Day | • Teaching the local community at a specific event<br>• Students plan creative activities for visitors to the school<br>• Creative summaries of the lessons presented in the classroom as a peer teaching (i.e., at every lesson two students summarized the previous lesson in a creative way) |
| | Implementation | The ability to make generalizations | | • Developing teaching plans for the LK Day which required dealing with diverse aspects and generalizing one's understanding of the ecosystem |
| | | The ability to think temporally | | • Students presented the ecosystem as a sequence of events. They presented a comparison between the population size in the past, present, and predictions for the future. |