AUTHORS	Eija Yli-Panula, Ilona Södervik, Ella Jeronen, Hanna Rantala
TITLE	Finnish primary school student teachers' systems thinking regarding sustainability in connection with reproduction, biodiversity and sustainable development
YEAR	2024
DOI	https://doi.org/10.5617/nordina.10385
VERSION	Publisher's PDF
CITATION	Yli-Panula, E., Södervik, I., Jeronen, E., & Rantala, H. (2024). Finnish primary school student teachers' systems thinking regarding sustainability in connection with reproduction, biodiversity and sustainable development. Nordina : Nordic Studies in Science Education, 20(2), 191–205. https://doi.org/10.5617/nordina.10385
LICENSE	CC BY

Eija Yli-Panula, Ph.D., Docent in Sustainability Education works as the Research Fellow (Emerita) at the Department of Teacher Education in the University of Turku and as visiting professor in the University of Murcia, Spain. Her research interests are in the field of teacher education and teaching and learning especially in natural sciences and sustainability education. https://orcid.org/0000-0001-8774-6566

Ilona Södervik (PhD, Docent in Education - specialising in life sciences pedagogy) is a University Lecturer at the Faculty of Education, University of Helsinki. Her research interests concern sustainability and learning and teaching of life sciences. https://orcid.org/ORCID-ID: 0000-0001-8575-487X

Eila Jeronen, is Emerita in University of Oulu and Docent in University of Oulu, University of Helsinki, and University of Lapland. She does research in Didactics, Educational Theory and Higher Education. Her research interests are teacher education and teaching and learning especially in the area of natural sciences, environmental education, sustainable development education, and health education. https://orcid.org/0000-0001-8610-2355

Hanna Rantala, Master of Sciences, has graduated from the Department of Biology, University of Turku, Finland. Her specialisation is in biology, geography and handicraft education. She has been working as the teacher in Basic Education and in Upper Secondary School.

EIJA YLI-PANULA
University of Turku, Finland and University of Murcia, Spain
eija.yli-panula@utu.fi

ILONA SÖDERVIK
University of Helsinki, Finland
ilona.sodervik@helsinki.fi

EILA JERONEN
University of Oulu, University of Helsinki, and University of Lapland, Finland
eila.jeronen@oulu.fi

HANNA RANTALA
University of Turku, Finland
hannarantala95@gmail.com

Finnish primary school student teachers' systems thinking regarding sustainability in connection with reproduction, biodiversity and sustainable development

Abstract

Systems thinking is considered an important skill when teaching biology and sustainable development in the 21st century. The key to understanding biodiversity and thus sustainability in biology is understanding reproduction as a phenomenon. The aim of this study is to analyse student teachers' systems thinking levels regarding sustainability in connection with reproduction, biodiversity and sustainable development. Second-year primary school student teachers from one Finnish university (N = 174) answered in a questionnaire, and their open-ended answers were categorized using content analysis. The results indicate that most of the student teachers had a relatively low level of systems thinking concerning sustainable development and its relation to the concepts of biodiversity and reproduction. The study also showed that student teachers with higher interest towards biology had a more sophisticated level of systems thinking. Teaching that emphasizes specific systems thinking skills and a comprehensive understanding of the broader context is essential for fostering an understanding of sustainability."

Keywords: sustainability, systems thinking, reproduction, student teachers, teacher education, content analysis

INTRODUCTION

In its ecological, economic and social dimensions, sustainable development includes a variety of interrelated cultural, health and political aspects. In the educational systems of many countries emphasizing economic growth, the citizenship skills needed in the global information economy are emphasized, with sustainability issues receiving less attention (Stevenson, 2007). This development has led to a conflict between economic growth and sustainability, with the former having increased consumption and brought with it negative environmental effects (Godard & Mainguy, 2008; Intergovernmental Panel on Climate Change, 2014). Systems thinking, which examines the interconnected parts of a system, could support a better understanding of the complexity of sustainable development. It is part of scientific thinking and can be regarded as a tool for learning and seeking paths to improve performance and quality (Draper, 1993).

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) published its first global assessment on the state of biodiversity and ecosystem decline in 2019. It states that 'nature is declining globally at rates unprecedented in human history – and the rate of species extinctions is accelerating, with grave impacts on people around the world now likely' (Díaz et al., 2019, p. 3). Globally, one key environmental problem is the population in humankind, which means keeping human reproduction within appropriate limits while also preventing the extinction of animal or plant species, such as those in isolated areas. While both asexual and sexual reproduction are biologically important factors for species survival and biodiversity, when they lead to overpopulation, a significant challenge to sustainable development is posed. Reproduction is a system, and a system can be defined as a set of things followed by one another; the system of reproduction is intrinsically bound to human–earth systems. Understanding complex and dynamic systems requires systems thinking skills (Clark & Zeegers, 2015; Martin, Brannigan, & Hall, 2007).

In both natural science education and sustainability education, systems thinking has been considered a crucial skill to teach (e.g. Unesco, 2017). Sustainability education is a multidisciplinary, collaborative, experiential and transformative education process (Jeronen, 2023; Moore, 2005). It includes research, dialogue, reflection and action development based on values and goals. Systems thinking skills can be developed at different grade levels using a wide range of teaching strategies (Karaarslan-Semiz, 2021) and teaching and learning methods (Palmberg, Hofman-Bergholm, Jeronen, & Yli-Panula, 2017).

In order for students to find learning content meaningful, students' previous knowledge and personal connections to the issues to be learned are important to integrate into the learning process (Levin, 2000). Because students' reactions to the outcome of their efforts can also shape their future behaviour (Immordino-Yang & Faeth, 2010), their views on sustainable development are crucial. However, this issue has not yet received sufficient attention (Aleixo, Leal, & Azeiteiro, 2021), particularly in matters of reproduction and biodiversity. The aim of the present study is to analyse the systems thinking levels of Finnish primary school student teachers regarding sustainability and to assess how they explain the relationship between reproduction, biodiversity and sustainable development. The goal of this survey is to encourage the developers of the curricula and teachers and student teachers to consider systems thinking in their teaching and to offer ideas about the levels of systems thinking that should be supported.

SYSTEMS THINKING AND EDUCATION

Conceptualizing systems thinking

There are many definitions of systems thinking. Peter Senge (1990) defines it as the discipline of seeing wholes and understanding interrelationships and changes instead of regarding situations as static. Frank Draper (1993) describes it as the capability of seeing the world as a multifaceted system in which all components are connected to one another. According to Korten (1995), systems thinking demands a willingness to seek out connections between problems and events. It supports the understanding of the processes included in the whole (Bunge, 2000) and the understanding of one's own role from a holistic perspective. Systems thinking is the ability to recognize different biophysical and social components and the interrelationships of systems in a given context (Sterling, 2003). According to Davidz and Nightingale (2008), systems thinking is an analytical and synthetic understanding of technical, social, temporal and multi-level interconnections, interactions and dependencies. Kasser (2019) states that systems thinking enables understanding interconnections and relationships between issues and understanding the world as a complex system. Moore et al. (2018), meanwhile, define systems thinking as the ability to identify, understand and synthesize interactions and interdependencies in the context assigned to a particular component.

All these definitions include the view that systems thinking is the ability to understand interrelationships that are often complex. According to Stave and Hopper (2007), there is a consensus about seven key components of systems thinking: recognizing interconnections, identifying feedback, understanding dynamic behaviour, differentiating types of flows and variables, using conceptual models, creating simulation models and testing policies.

Systems thinking is based on critical thinking and reflection and requires the ability to judge and act (Sterling, 2009). According to Ben-Zvi-Assaraf and Orion (2005) and Senge (1990), systems thinking is a combination of different skills and constitutes a higher-order way of thinking. In addition, Batzri, Ben-Zvi-Assaraf, Cohen, and Orion (2015), Keynan, Ben-Zvi-Assaraf, and Goldman (2014) and Palmberg et al. (2017) have carried out studies concerning systems thinking and its conceptualization in science education. Systems thinking can be taught and learned and serve as a component of behaviour change interventions (Moore et al., 2018).

Systems thinking in biology education and sustainability education

Systems thinking has received increasing attention from educators in recent years and has been studied in different disciplines such as science education and biology education (e.g. Fanta, Braeutigam, & Riess, 2020; Zangori & Koontz 2017) and in sustainability education (Ateskan & Lane, 2018; Connell, Remington, & Armstrong, 2012; Palmberg et al., 2017; Remington-Doucette, Hiller Connell, Armstrong, & Musgrove, 2013; Sandri, 2013). Even people with a strong science, technology, engineering and mathematics background do not always understand complex dynamical systems (Voulvoulis et al., 2022) and tend to explain them using solely causal thinking (Plous, 1993). While causal thinking is part of systems thinking (Sheehy, Wylie, McGuinness, & Orchard, 2000), it alone is not sufficient to understand the network formed by complex phenomena and to adopt a different way of thinking about the relationship between humans and the world (Allen, Cunliffe, & Easterby-Smith, 2019). Redman and Wiek (2021) list four other competencies to solve complex phenomena being futures thinking, action-oriented, values thinking and collaboration competency.

While research has shown that education does not sufficiently develop students' systems thinking skills (Palmberg et al., 2017), Riess and Mischo (2017) and Karaarslan-Semiz and Teksöz (2020) have shown that pre-service science teachers' systems thinking skills can in fact be nurtured and enhanced. They found 12 systems thinking skills in outdoor education for sustainable development and science education; based on interviews, their evaluation of the systems thinking skills of pre-service teachers was categorized into four levels: pre-aware, emerging, developing and mastery. The pre-service teachers were shown to develop systems thinking skills which were not able to be analysed in the implementation stage, such as recognizing the cyclical nature of systems, empathy among non-human beings, developing a sense of place and adapting a systems thinking perspective to one's personal life. Riess and Mischo (2010) define systems thinking as an ability to recognize and describe complex aspects of reality as systems. According to Riess and Mischo (2010), Schuler, Fanta, Rosenkraenzer, & Riess (2017), the essential aspects of systems thinking include the ability to identify central parts of systems and recognize dimensions of the passage of the time.

The primary focus of the systems approach is on the interrelationships of a system's components (Bertalanffy, 1968), with the goal of being able to connect biological components, for example, by using an approach that advocates viewing the issue at hand as a whole. This runs contrary to the traditional approach that understands a subject by analysing its individual parts. Every biological system is part of a larger and more complex system, and humans themselves are part of earth's vast biological diversity. For both humans and other species, habitats and the relationships between them are crucial. In its boundless versatility, nature produces food, energy, medicines, fibres and other essential commodities. It also maintains good air quality, clean water and fertile soil and produces a climate that supports life (Díaz et al., 2019.) According to Riess and Mischo (2010), populations based on reproduction in biology can comprise part of ecosystems and ultimately the integral biosphere, which is an integral part of the planet and climate. Skill at systems thinking is essential for comprehending systems and interactions, which is why several researchers have sought to show that it can be fostered not only at the primary and middle school levels (Ben-Zvi-Assaraf & Orpaz, 2010; Evagorou, Korfiatis, Nicolaou, & Constantinou, 2009; Hmelo-Silver, Jordan, Eberbach, & Sinha, 2017; Sommer & Luecken, 2010) but also at the high school level concerning the system of the human body (Tripto, Ben-Zvi-Assaraf, Snapir, & Amit, 2017) and regarding ecology through outdoor learning (Karaarslan-Semiz & Teksöz, 2022). According to Kim and Senge (1994), systems thinking can be used when groups need to work, experience and learn together.

Sustainability education, systems thinking, biodiversity and reproduction in Finland´s biology curricula

In Finland's biology curricula, the terms 'sustainability education' and 'systems thinking' are not even mentioned, although the concept of sustainable development does appear. In basic education, the importance of the biodiversity is emphasized. The content consists of the fundamentals of the structures and functions of living organisms, diversity of habitats and heredity and evolution. These areas are related to, for example, the preservation of natural diversity and changes in the surrounding environment. (Finnish National Agency for Education, 2017). In the 'Life cycle' section in secondary school biology, the central contents are sexual and asexual reproduction, growth, development and death, while the 'Evolution' section deals with natural selection, adaptation and the emergence and extinction of species (Finnish National Agency for Education, 2019). Group work, co-operational and problem-solving skills and experiential and inquiry-based learning have been reported to be important when supporting students' skills to influence and participate in the development of their immediate environment and keep it viable (e.g. Hmelo-Silver, 2004, Hmelo-Silver, Duncan, & Chinn, 2007). Students are also guided to understand the notions of sustainable lifestyle and global responsibility (Finnish National Agency for Education, 2017, 2019). In Finland's teacher education curricula, sustainability education and competencies concerning teaching sustainability are mentioned (University of Turku, 2022).

RESEARCH AIM AND QUESTIONS

The aim of this study is to analyse Finnish primary school student teachers' levels of systems thinking regarding sustainability and how they explain the relationships between reproduction, biodiversity and sustainable development. The responses of the student teachers to a survey questionnaire were examined using content analysis. The goal of the research is to encourage teachers and student teachers to pay attention to systems thinking and to offer ideas about the levels of systems thinking that should be supported in their teaching. The study is framed by two research questions:

1. How do student teachers describe the relationships between reproduction, biodiversity and sustainable development?
2. What level(s) of systems thinking do the student teachers' answers reflect?

In addition, the student teachers' interest in biology in connection with their level of systems thinking was an area of focus.

MATERIAL AND METHODS

Participants

The participants were second-year student teachers (*N* =174; 138 female, 35 male, 1 other) from a single Finnish university. A total of 154 (88.5%) of participants had completed the compulsory biology course, which is worth 3 ECTS. The participants' age cohorts were as follows: < 25 (71.8%), 25–35 (18.4%) and > 35 (9.8%).

The study was performed according to the ethical guidance of the Finnish National Board on Research Integrity. Thus, participation was voluntary, and the students had the ability to withdraw from the research at any time without consequence.

Design and measures

Because cohorts of student teachers are relatively small, the study was conducted over two consecutive years. A total of 86 second-year student teachers participated in the study in the first year (2019); 88 students took part in the second year (2020). The teacher education curriculum was unchanged across both years, and the biology course teacher at the university where the study was carried out was the same.

The participants completed the questionnaire individually in a controlled situation in a regular lecture hall context in November 2018 and September 2020. The students had approximately 30 minutes to answer the questions; the answers were provided in Finnish, the students' first language. The questionnaire was pre-tested by three subject student teachers.

Background information measures on student teachers included the year in which they participated in the study (2018 or 2020), their general interest in biology (a scale of 1–10) and whether or not they had completed the compulsory basic biology course (3 ECTS) for the elementary school level.

Student teachers' systems thinking was measured with an open-ended essay question based on a web-based questionnaire (www.webropolsurveys.com). The student teachers were asked the following question: "How are the concepts of reproduction, biodiversity (i.e. biological diversity) and sustainable development related to each other?" This particular topic was chosen because sustainability, reproduction and biodiversity are taught in the compulsory biology didactics in Finnish teacher education, and the student teachers were thus expected to have appropriate understandings of those topics. The task and analytical protocol were piloted with two biology subject student teachers; a model answer written by them including seven systems thinking levels is presented below.

- Sustainable development, biodiversity and reproduction are concepts in biology that are closely connected to each other (Level 1).
- Sustainable development is needed so that biodiversity is preserved and thus the reproduction of organisms is secured. With the help of sustainable development measures, the aim is to secure the habitats of different species so that organisms can grow and reproduce (Level 2).
- Sustainable development can be divided into three different levels: ecological, economic and social sustainable development. The goal of ecological sustainable development is the preservation of natural diversity and ecosystems, which enables a wide biodiversity. Even biodiversity is different, as there is inter-species diversity and intra-species diversity; the latter affects reproduction (Level 3).
- For example, poaching reduces diversity within a species when its population decreases. An inherently homogeneous population is susceptible to disease and illness and this reduces the generation of vigorous new generations and further reduces the size of populations. When fishing in accordance with the principles of sustainable development, diversity within species is safeguarded (Level 4).
- Safeguarding biodiversity is also beneficial for humans, such as in the production of food and medicine. By promoting sustainable development and biodiversity, people protect their own lives on earth (Level 5).
- Each species has its own place in the ecosystem. Since the ecosystem is a dynamic and interactive entity, the disappearance of even one species can cause major changes. That is why it is important to take care of biodiversity including the genetic diversity that ensures the emergence of vibrant new generations. Lost species cannot be recovered, and destroyed ecosystems will not fully recover, resulting in significant changes in future evolution (Level 6).
- Modelling of an experiment in the ecosystem leading to disappearance of species is ethically problematic in practice, but there are examples of projects aiming to endorse survival of endangered species by refreshing / repairing the ecosystem the species are part of, e.g. by planting a specific species of eucalyptus for koalas in Australia or preventing coral bleaching on the Great Barrier Reef by planting *Symbiodiniaceae*, on which coral reproduction and flourishing depend. Without such operations, the existence of the Great Barrier Reef and its diverse biota is seriously threatened. This in turn would have massive consequences for the oceans and, by extension, for all the Earth's ecosystems, as the viability of the planet depends on the state of the oceans. (Level 7)

In this study, we use the term 'level' to describe the different categories of the system thinking model. At the upper levels, it is thought that more complex and thus more sophisticated systems thinking is required. However, it should be noted that these levels are not automatically constructed on top of each other in a logically cumulative manner, but that a student may present statements from the 'higher levels' of systems thinking model without automatically resulting in that all of the requirements from the 'lower levels' of the model being met as well. This solution has been made because it is known from learning research that human knowledge structures are layered in nature in the sense that a learner can for example have both misconceptions and scientific conceptions simultaneously and what knowledge is used depends on many factors (Vosniadou, 2012). Thus, to avoid over-interpreting students' understanding, the scoring system has been designed in such a way that students can demonstrate, for example, level 7 thinking in their answer, but we do not automatically assume that they master levels 1-6.

Data analysis

A mixed methods approach was used to analyse the data. First, student teachers' systems thinking levels were categorized based on their written answers using a theory-driven content analysis (Table 1). The categories were formed based on Stave and Hopper's (2007) original classification, which was further developed by Palmberg et al. (2017). The answer of each participant could represent several levels of systems thinking. In addition to categorizing the answers, a sum score was calculated for each student teacher. One point was awarded for an answer representing Level 1 systems thinking, two points for an answer representing Level 2, three points for an answer representing Level 3 and so on.

A biology teacher (the fourth author) categorized all student teachers' answers, with inter-rater analysis carried out for 15% of the data by a senior university lecturer and biology teacher (the second author). The inter-rater agreement of the analysis was 80%, which is considered high in this type of qualitative analysis (O'Connor & Joffe, 2020).

The differences between the student teacher groups (based on year and completion of the biology course) were quantitatively analysed with independent samples *t*-tests. Additionally, the student teachers' interest in biology was compared with their systems thinking level using a Pearson correlation test.

Table 1. Analytical categories of levels of systems thinking, adapted from Stave and Hopper (2007) and Palmberg et al. (2017).

	Level 0	No level of systems thinking	
Basic level	Level 1	Recognising interconnections	Identify parts of a system
	Level 2	Identifying feedback	Recognise chains of causal links. Identify closed loops.
	Level 3	Understanding dynamic behaviour	Explain the behaviour of a particular causal relationship or feedback loop. Explain the behaviour of linked feedback loops.
Intermediate level	Level 4	Differentiating types of variables and flow	Describe the parts and levels of the system according to their functions.
	Level 5	Using conceptual models	Use a conceptual model of system structure to suggest potential solutions to a problem.
Advanced level	Level 6	Creating simulation models	Build a functioning model. Operate the model. Validate the model.
	Level 7	Testing policies	Hypothesize the effect of changes. Use model to test the effect of changes. Interpret model output with respect to problem.

As for the trustworthiness of the study (Elo et al., 2014), its design and implementation were negotiated among the researchers throughout the research process. The study procedures were carefully documented to review and verify data throughout the study. The analysis of the data was carried out independently by two researchers. At the end of the analytical process, the researchers compared and discussed their classifications until a unified view was reached. The results were also compared with previous studies.

RESULTS

First, we checked whether there were differences between student teachers who had completed the compulsory biology course at university and those who had not. There was no statistical difference between the groups in their level of systems thinking (t (172) = 1,347; p = .180). We also checked whether there were differences in student teachers' level of systems thinking across years; there were also no differences in this regard (t (172) = -.191; p = .849). Thus, all participants were studied as one sample in further analyses.

The investigation made it clear that most student teachers had a relatively low level of systems thinking concerning sustainable development related to the concepts of biodiversity and reproduction (Table 2). Indeed, 14.4% of the answers were categorized as a total absence of systems thinking (Level 0). A large majority (77%) of the student teachers were categorized as having a basic grasp (Levels 1–3) of systems thinking, and only 8.6% were identified as having intermediate or advanced skills in systems thinking (Levels 4–7).

Table 2. The distribution of student teachers' answers across systems thinking Levels 0–7

	Level 0	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7
n (%)	25 (14,4)	16 (9,2)	80 (46,0)	38 (21,8)	0 (0,0)	6 (3,4)	7 (4,0)	2 (1,1)

Several of the student teachers' answers (f = 25; 14.4%) were categorized as Level 0, which meant they showed no indication of systems thinking. These student teachers were unable to recognize or identify connections between specific concepts. Typical answers at this level included *'All are related to biology and the cycle of life'* (ID 4), and *'All are matters of biology, all are related to nature and our environment, but I think they have nothing more in common'* (ID 8).

Answers categorized as Level 1 showed an awareness of simple interconnections, as the following quotes suggest: *'Sustainable development is related to the diversity of nature and thereby the possibilities of reproduction of organisms'* (ID 15); *'They have a great influence on each other. Reproduction affects biodiversity and biodiversity affects sustainable development'* (ID 129); and *'So that all living things work in cooperation with each other. And in order for us to have sustainable development and for all living things to do well now and in the future, everything affects everything – thinking is an important thing to learn in school'* (ID 154).

Almost half (44.7%) of the student teachers' answers were categorized as Level 2, indicating that the answers were rather superficial and involved only identification of certain interrelations between concepts without offering any justification of or explanation for those connections. Typical answers categorized as Level 2 were as follows: 'Sustainable development and continuity require the preservation of biodiversity and controlled reproduction' (ID 13); *'Reproduction can either increase or decrease natural diversity; that is, biodiversity and sustainable development mean nature remaining diverse'* (ID 19); *'Sustainable development guarantees the reproduction of species and maintains biodiversity'* (ID 41); *'Sustainable development enables good biodiversity. In good biodiversity, reproduction is balanced between organisms'* (ID 93); and *'Sustainable development requires controlled reproduction, awareness of biological diversity and its preservation. If one of these three areas is removed, the other areas will not be able to function well enough'* (ID 144).

Answers categorized as Level 3 included basic descriptions of interconnections and feedback loops. These answers were slightly longer but considered the phenomenon only from a single perspective, indicating that these student teachers remained in the basic stratum of systems thinking, although they were at the top end of that range. The following examples represent Level 3 answers:

> *Reproduction and biodiversity are related to each other in such a way that without reproduction, biodiversity would not remain at the same level. On the other hand, reproduction is related to sustainable development in such a way that if there are, for example, too many people, the carrying capacity of nature is insufficient. In terms of sustainable development, it would be beneficial if biodiversity was as 'good' (versatile) as possible.* (ID 5)

> *Biodiversity is a prerequisite for the reproduction of different species and to make the living conditions of different organisms possible. Biodiversity can be protected with the help of sustainable development, which in turn is connected to the reproductive opportunities of different species.* (ID 43)

> *In order for any species to remain healthy and exist (sustainable development of the species), it is important that there be sufficient biodiversity among the reproducing individuals. Inbreeding and the emphasis of characteristics harmful to species development are avoided.* (ID 73)

> *The principles of sustainable development aim to protect biodiversity in terms of both species and ecosystems. In turn, the reproduction and well-being of species depend on the diversity of nature. In addition, various human-caused changes such as pollution can directly affect organisms and their vitality and reproduction.* (ID 180)

These answers at Levels 1 to 3 belonged to the basic stratum of systems thinking (Stave & Hopper, 2007). Answers in Levels 4 and 5 are classified as intermediate (Stave & Hopper, 2007), but none of the participants' answers was assigned to Level 4, and only a few qualified as Level 5. At that level, one student teacher related a story of the expected effect of an action on a given problem and suggested a potential solution. The following is an example of a Level 5 answer:

> *Biodiversity therefore means biological diversity. Biodiversity is important to cherish, and therefore the concept of sustainable development is related to it. For example, it would not be good to cut down trees from rainforests, because that affects species that live in trees, as well as species that eat leaves from trees (and all other species, because plants produce oxygen, etc.). Animals and plants must have good reproductive opportunities so that species do not become extinct, and nature continues to be a diverse entity.* (ID 105)

The answers at Levels 6 and 7 represent the most advanced stage of systems thinking. At Level 6, the student teachers' answers included written simulation models concerning reproduction, biodiversity or sustainable development that were suitable for comparison to behaviour observed on earth, such as human activity. The following are examples of Level 6 answers:

> *Reproduction guarantees the conservation of the species, which maintains the diversity of nature. Sustainable development, on the other hand, guarantees that living conditions remain favourable for species so that they can multiply.* (ID 52)

> *The rate of reproduction of different species is linked to biodiversity in such a way that if a species does not increase, it becomes extinct, reducing biodiversity. Biodiversity, on the other hand, is linked to sustainable development, because changes in it affect everything on earth, such as other species and the climate. Human reproduction or lack of reproduction also has an impact on sustainable development, because human activity on earth is relevant to the environment.* (ID 76)

> *The increase in organisms increases biodiversity, because the more different organisms we have, the more diverse nature is. Sustainable development supports the preservation of habitats and the ability of organisms to live longer and produce offspring capable of reproduction. Sustainable development also helps endangered organisms to survive.* (ID 145)

At Level 7, the student teachers offered descriptions of the expected outcomes of a given change, such as burdens on the earth and how biodiversity guarantees the well-being of the system, indicating the most advanced systems thinking skills. The following quotes are examples of Level 7 answers:

> *A sustainable way of life should protect the conservation of diversity in the future. If we continue to live on earth the way we are now, we will continue to destroy biodiversity. At the moment, every individual born burdens the earth more.* (ID 108)

> *Biodiversity is limited if some species are no longer able to reproduce in a certain environment; for example, if too many forests are cut down, the plants and animals in those areas will no longer able to obtain enough food and will be reduced [in number]. Animals may not be able to carry out their species-typical behaviour in a changing environment; their territory is reduced or is expanded to atypical areas, such as cities "urban bear". For example, cutting down rainforests destroys an area's biodiversity and also affects the well-being of the entire planet, because rainforests are the 'lungs of the earth'. Taking care of biodiversity guarantees the well-being of a system that has developed over millions of years and improves the survival of humans on Earth.* (ID 143)

The student teachers' interest in biology was an average of 6.89 out of 10 (Min, 1.00; Max, 10.00; SD, 1.80), indicating an overall moderate level interest in biology. That interest correlated positively with the level of systems thinking (r = .268; p > .01), meaning that those with a greater interest in biology had a more sophisticated level of systems thinking.

DISCUSSION

Systems thinking among Finnish student teachers in the context of biodiversity and sustainable development

Systems thinking has been identified as an important 21st-century skill in teaching biology and sustainability (Ben-Zvi-Assaraf & Orion, 2010; Chandi, 2008; Keynan et al., 2014; Shepardson, Roychoudhury, Hirsch, Niyogi, & Top, 2014). Palmberg et al. (2017) studied the systems thinking levels of student teachers in Nordic countries in biodiversity education and sustainability contexts. Their study focused on student teachers' systems thinking about the ecological dimension of sustainability, especially their views about the relationship between species identification, biodiversity and sustainable development. The findings concerning student teachers' systems thinking were intended to support the redesign of university teacher education programmes to take into account the teaching and learning competencies needed to understand and convey the complexity of sustainability (cf. Sterling, 2017).

One very important issue in biology is to understand reproduction as a phenomenon, as it is a prerequisite for understanding biodiversity and furthering sustainability. It is important to understand it as part of a system. The awareness of reproduction supports people in grasping how their own life choices can influence the diversity of animal and plant species in an area and thus a sustainable way of life in that area. In the present study, systems thinking concerning the connections between reproduction, biodiversity and sustainable development as a complex system was in focus for the first time. The results show that most student teachers lack the ability to use systems thinking to understand those three issues as part of a complex system. Such complex systems are not easy to understand because understanding them requires special systems thinking skills (Riess & Mischo, 2010).

Two key findings are that six of the seven levels of systems thinking and no systems thinking were found among the student teachers' answers and that most student teachers had a relatively low level of systems thinking concerning sustainable development and the concepts of biodiversity and reproduction; quite a number of students demonstrated no ability to engage in systems thinking. A similar finding was reported in Palmberg et al.'s (2017) study in three Nordic countries regarding the relationship between species identification, biodiversity and sustainable development. Both sets of results confirm that phenomena connected to sustainable development are extremely difficult to accurately connect with each other, especially at higher levels of systems thinking. These results are similar to those in Zangori and Koontz (2017), who reported that upper-level undergraduate biology students did not fully understand the connection between the elements of climate change even when they did express an understanding of cause and effect and rarely made connections to system feedback even after studying these issues for a certain period of time.

Less than one tenth of student teachers were identified as having an intermediate or advanced level of systems thinking. This result is in line with the results in Dutton-Lee (2015): primary school students had low levels of systems thinking concerning the context of the water cycle. In the student teachers answers the advanced 7th level appeared rarely. Systems thinking at this level requires the student teachers to understand socio-scientific issues and it also requires examining the causal connections within and between the systems and analyzing the possible results of the system from the perspective of different stakeholders (Sadler et al., 2007). Learners who do not have experience studying problems from a systems perspective often do not understand enough the complexity of issues (Liu et al., 2011; Yang, 2005). So, it is important to provide student teachers with tools to promote systems thinking and other epistemic tools (Ke at al. 2020; Markauskaite & Goodyear, 2014), to facilitate knowledge and construction and justification.

Limitations and future directions

The present study offers interesting and important findings about Finnish primary school student teachers' systems thinking skills regarding sustainability development in relation to reproduction and biodiversity. However, the following aspects need to be considered before generalizing the results. In the present study, only questionnaires were used, and it would be valuable to conduct interviews in the future studies to obtain a deeper understanding of the students' ideas and systems thinking skills.

According to our findings, systems thinking was more sophisticated in student teachers who were more interested in biology. It is also known that didactic knowledge related to subjects supports student teachers' understanding systems, fosters their systems thinking, increases their pedagogical content knowledge and trains them to teach about systems (Schuler et al., 2017). Palmberg et al. (2017) showed that older Norwegian student teachers tend to demonstrate more systems thinking than other Nordic student teachers in the same age cohort. Thus, it appears that both interest in subject knowledge, and teaching strategies and life experiences have effects on student teachers' systems thinking skills. Elucidating these and other factors affecting systems thinking skills of the student teachers is an important topic for further research. Therefore, one suggestion for future research is to compare differing systems thinking teaching strategies and practices in teacher education to foster student teachers' higher-order systems thinking in biology. In addition, through a different research design, a broader and more in-depth picture of the factors affecting student teachers' systems thinking is obtained than based on a survey alone.

REFERENCES

Aleixo, A. M., Leal, S., & Azeiteiro, U. M. (2021). Higher education students' perceptions of sustainable development in Portugal. *Journal of Cleaner Production*, 327, 129429. https://doi.org/10.1016/j.jclepro.2021.129429

Allen, S., Cunliffe, A. L. & Easterby-Smith, M. (2019). Understanding sustainability through the lens of ecocentric radical-reflexivity: Implications for management education. *Journal of Business Ethics*, 154, 781–795. https://doi.org/10.1007/s10551-016-3420-3

Ateskan, A., & Lane, J. F. (2018). Assessing teachers' systems thinking skills during a professional development program in Turkey. *Journal of Cleaner Production*, 172, 4348–4356. https://doi.org/10.1016/j.jclepro.2017.05.094

Batzri, O., Ben-Zvi-Assaraf, O., Cohen, C., & Orion, N. (2015). Understanding the earth systems: Expressions of dynamic and cyclical thinking among university students. *Journal of Science Education and Technology*, *24*(6), 761–775. https://doi.org/10.1007/s10956-015-9562-8

Ben-Zvi-Assaraf, O., & Orion, N. (2005). Development of system thinking skills in the context of earth system education. *Journal of Research in Science Teaching*, *42*(5), 518–560. https://doi.org/10.1002/tea.20061

Ben-Zvi-Assaraf, O., & Orion, N. (2010). Four case studies six years later: Developing systems thinking skills in junior high school and sustaining them over time. *Journal of Research in Science Teaching*, *47*(10), 1253–1280. https://doi.org/10.1002/tea.20383

Ben-Zvi-Assaraf, O., & Orpaz, I. (2010). "The life at the poles" study unit: Developing junior high school students' ability to recognize the relations between earth systems. *Research in Science Education*, *40*(4), 525–549. doi:10.1007/s11165-009-9132-2

Bertalanffy, L. (1968). *General system theory*. New York, NY: George Braziller Inc.

Bunge, M. (2000). Systemism: The alternative to individualism and holism. *Journal of Socio-Economics*, *29*(2), 147–157. https://doi.org/10.1016/S1053-5357(00)00058-5

Chandi, S. S. (2008). *Systems thinking as a teaching and learning tool for biology education* [Doctoral dissertation, University of Strathclyde]. https://doi.org/10.48730/8c9v-f519

Clark, I. F., & Zeegers, Y. (2015). Challenging students' perceptions of sustainability using an Earth Systems Science approach. *Journal of Geography in Higher Education*, *39*(2), 260–274. https://doi.org/10.1080/03098265.2015.1010142

Connell, K. Y. H., Remington, S. M., & Armstrong, C. M. (2012). Assessing systems thinking skills in two undergraduate sustainability courses: A comparison of teaching strategies. *Journal of Sustainability Education*, *3*. http://hdl.handle.net/2097/13783

Davidz, H. L., & Nightingale, D. J. (2008). Enabling systems thinking to accelerate the development of senior systems engineers. *Systems Engineering*, *11*(1). https://doi.org/10.1002/sys.20081

Díaz, S., Settele, J., Brondízio, E. S., Ngo, H. T., Guèze, M., Agard, J., ... Zayas, C. N. (Eds.). (2019). *Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. Bonn: IPBES Secretariat. https://www.ipbes.net/global-assessment

Draper, F. (1993). A proposed sequence for developing systems thinking in a grades 4–12 curriculum. *System Dynamics Review*, *9*, 207–214. https://doi.org/10.1002/sdr.4260090209

Dutton-Lee, T. (2015). *Science teachers' representational competence and systems thinking* [Doctoral dissertation, North Carolina State University]. https://repository.lib.ncsu.edu/bitstream/handle/1840.16/10281/etd.pdf?sequence=2

Elo, S., Kääriäinen, M., Kanste, O., Pölkki, T., Utriainen, K., & Kyngäs, H. (2014). Qualitative content analysis: A focus on trustworthiness. *SAGE Open*, *4*(1). https://doi.org/10.1177/2158244014522633

Evagorou, M., Korfiatis, K., Nicolaou, C., & Constantinou, C. (2009). An investigation of the potential of interactive simulations for developing systems thinking skills in elementary school: A case study with fifth-graders and sixth-graders. *International Journal of Science Education*, *31*(5), 655–674. https://doi.org/10.1080/09500690701749313

Fanta, D., Braeutigam, J., & Riess, W. (2020). Fostering systems thinking in student teachers of biology and geography: An intervention study. *Journal of Biological Education*, *54*(3), 226–244. https://doi.org/10.1080/00219266.2019.1569083

Finnish National Agency for Education. (2017). *National Core Curriculum for Basic Education for Adults*. Helsinki. https://www.oph.fi/en/statistics-and-publications/publications/national-core-curriculum-basic-education-adults-2017

Finnish National Agency for Education. (2019). *National core curriculum for general upper secondary education 2019*. Helsinki. https://verkkokauppa.oph.fi/EN/page/product/national-core-curriculum-for-general-upper-secondary-education-2019/2763815

Godard, O., & Mainguy, G. (2008). The Stern Review on the Economics of Climate Change: Contents, insights and assessment of the critical debate. *S.A.P.I.EN.S*, *(1)*1.

Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review, 16*(3), 235–266.

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: A response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist, 42*(2), 99–107.

Hmelo-Silver, C. E., Jordan, R., Eberbach, C., & Sinha, S. (2017). Systems learning with a conceptual representation: A quasi-experimental study. *Instructional Science*, *45*(1), 53–72. https://doi.org/10.1007/s11251-016-9392-y

Immordino-Yang, M. H., & Faeth, M. (2010). The role of emotion and skilled intuition in learning. In D. A. Sousa (Ed.), *Mind, brain and education* (pp. 69–84). Bloomington, IN: Solution Tree Press.

Intergovernmental Panel on Climate Change. (2014). *Climate change: Impacts, adaptation, and vulnerability. Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

Jeronen, E. (2023). Sustainable education. In S. O. Idowu, R. Schmidpeter, N. Capaldi, L. Zu, M. Del Baldo, & M. Abreu (Eds.), *Encyclopedia of Sustainable Management*. Cham: Springer. https://doi.org/10.1007/978-3-031-25984-5_237

Karaarslan-Semiz, G. (2021). Systems thinking research in science and sustainability education: A theoretical note. In E. Jeronen (Ed.), *Transitioning to quality education* (pp. 39–62). MDPI Books. https://doi.org/10.3390/books978-3-03897-893-0-3

Karaarslan-Semiz, G. (2022). Outdoor education for sustainability with systems thinking perspective. In G. Karaarslan-Semiz (Ed.), *Education for sustainable development in primary and secondary schools* (pp. 39–53). Cham: Springer. https://doi.org/10.1007/978-3-031-09112-4_4

Karaarslan-Semiz, G., & Teksöz, G. (2020). Developing the systems thinking skills of pre-service science teachers through an outdoor ESD course. *Journal of Adventure Education and Outdoor Learning*, *20*(4) 337–356. https://doi.org/10.1080/14729679.2019.1686038

Kasser, J. E. (2019). *Systems thinker's toolbox: Tools for managing complexity*. London: Routledge.

Ke, L., Sadler, T.D., Zangori, L., & Friedrichsen, P.J. (2020). Students' perceptions of socio-scientific issue-based learning and their appropriation of epistemic tools for systems thinking. *International Journal of Science Education, 42* (8), 1339-1361. https://doi.org/10.1080/09500693.2020.1759843

Keynan, A., Ben-Zvi-Assaraf, O., & Goldman, D. (2014). The repertory grid as a tool for evaluating the development of students' ecological system thinking abilities. *Studies in Educational Evaluation*, *41*, 90–105. https://doi.org/10.1016/j.stueduc.2013.09.012

Kim, D. H., & Senge, P. M. (1994). Putting systems thinking into practice. *System Dynamics Review*, *10*(2–3), 277–290. https://doi.org/10.1002/sdr.4260100213

Korten, D. (1995). *When corporations rule the world*. San Francisco, CA: Berrett-Koehler.

Liu, S.-Y., Lin, C.-S., & Tsai, C.-C. (2011). College students' scientific epistemological views and thinking patterns in socioscientific decision making. *Science Education, 95*(3), 497–517. https://doi.org/10.1002/sce.20422

Levin, B. (2000). Putting students at the centre in education reform. *Journal of Educational Change*, *1*, 155–172. https://doi.org/10.1023/A:1010024225888

Martin, S., Brannigan, J., & Hall, A. (2007). Sustainability, systems thinking and professional practice. *Journal of Geography in Higher Education*, *29*, 79–89. https://doi.org/10.1080/03098260500030389

Markauskaite, L., & Goodyear, P. (2018). Epistemic fluency and professional education. Innovation, knowledgeable action and actionable knowledge. Springer, Netherlands.

Moore, J. (2005). Is higher education ready for transformative learning? A question explored in the study of sustainability. *Journal of Transformative Education*, *3*(1), 76–91. https://doi.org/10.1177/1541344604270862

Moore, S. M., Komton, V., Adegbite-Adeniyi, C., Dolansky, M. A., Hardin, H. K., & Borawski, E. A. (2018). Development of the Systems Thinking Scale for Adolescent Behavior Change. *Western Journal of Nursing Research*, *40*(3),375–387. https://doi.org/10.1177/0193945917697219

O'Connor, C., & Joffe, H. 2020. Intercoder Reliability in Qualitative Research: Debates and Practical Guidelines. *International Journal of Qualitative Methods 19*, 1-13. doi.org/10.1177/1609406919899220

Palmberg, I., Hofman-Bergholm, M., Jeronen, E., & Yli-Panula, E. (2017). Systems thinking for understanding sustainability? Nordic student teachers' views on the relationship between species identification, biodiversity and sustainable development. *Education Sciences*, *7*(3), 72. https://doi.org/10.3390/educsci7030072

Plous, S. (1993). *The psychology of judgment and decision making.* New York, NY: McGraw Hill.

Redman, A., & Wiek., A. (2021). Competencies for Advancing Transformations Towards Sustainability. *Frontiers in Education, 6* (785), 1-11. https://doi.org/10.3389/feduc.2021.785163

Remington-Doucette, S. M., Hiller Connell, K. Y., Armstrong, C. M., & Musgrove, S. L. (2013). Assessing sustainability education in a transdisciplinary undergraduate course focused on real-world problem solving: A case for disciplinary grounding. *International Journal of Sustainability in Higher Education*, *14*(4), 404–433. https://doi.org/10.1108/IJSHE-01-2012-0001

Riess, W., & Mischo, C. (2010). Promoting systems thinking through biology lessons. *International Journal for Science Education*, *32*(6), 705–725. https://doi.org/10.1080/09500690902769946

Sadler, T. D., Barab, S. A., & Scott, B. (2007). What do students gain by engaging in socioscientific inquiry? *Research in Science Education, 37*(4), 371–391. https://doi.org/10.1007/s11165-006-9030-9

Sandri, O. J. (2013). Exploring the role and value of creativity in education for sustainability. *Environmental Education Research*, *19*, 765–778. https://doi.org/10.1080/13504622.2012.749978

Schuler, S., Fanta, D., Rosenkraenzer, F., & Riess, W. (2017). Systems thinking within the scope of education for sustainable development (ESD): A heuristic competence model as a basis for (science) teacher education. *Journal of Geography in Higher Education*, *42*(2), 192–204. https://doi.org/10.1080/03098265.2017.1339264

Senge, P. M. (1990). *The fifth discipline: The art and science of the learning organization*. New York: Currency Doubleday.

Sheehy, N., Wylie, J., McGuinness, C., & Orchard, G. (2000). How children solve environmental problems: Using computer simulations to investigate systems thinking. *Environmental Education Research*, *6*(2), 109–126. https://doi.org/10.1080/713664675

Shepardson, D. P., Roychoudhury, A., Hirsch, A., Niyogi, D., & Top, S. M. (2014). When the atmosphere warms it rains and ice melts: Seventh grade students' conceptions of a climate system. *Environmental Education Research*, *20*(3), 333–353. https://doi.org/10.1080/13504622.2013.803037

Sommer, C., & Luecken, M. (2010). System competence – Are elementary students able to deal with a biological system? *Nordic Studies in Science Education*, *6*(2), 125–143. https://doi.org/10.5617/nordina.255

Stave, K. A., & Hopper, M. (2007). What constitutes systems thinking? A proposed taxonomy. In J. Sterman, R. Oliva, R. S. Langer, J. I. Rowe, & J. M. Yanni (Eds.), *Proceedings of the 25th In-*

ternational Conference of the System Dynamics Society, Boston, MA, USA, 29 July–2 August 2007.

Sterling, S. (2003). *Whole systems thinking as a basis for paradigm change in education: Explorations in the context of sustainability* [Doctoral dissertation, University of Bath]. http://www.bath.ac.uk/cree/sterling/sterlingthesis.pdf

Sterling, S. (2009). Sustainable education. In D. Gray, L. Colucci-Gray, & E. Camino (Eds.), *Science, society and sustainability: Education and empowerment for an uncertain world* (pp. 105–118). New York, NY: Routledge.

Sterling, S. (2017). Assuming the future: Repurposing education in a volatile age. In B. Jickling, & S. Sterling, S. (Eds.), *Post-Sustainability and Environmental Education* (pp. 31–45). Cham: Palgrave Macmillan. https://doi.org/10.1007/978-3-319-51322-5_3

Stevenson, R. B. (2007). Schooling and environmental/sustainability education: From discourses of policy and practice to discourses of professional learning. *Environmental Educational Research*, *7*(13), 265–285. https://doi.org/10.1080/13504620701295650

Tripto, J., Ben-Zvi-Assaraf, O., Snapir, Z., & Amit, M. (2017). How is the body's systemic nature manifested amongst high school biology students? *Instructional Science*, *45*(1), 73–98. https://doi.org/10.1007/s11251-016-9390-0

University of Turku. *Multidisciplinary studies in the subjects and cross-curricula themes taught in basic education*. Turku. https://opas.peppi.utu.fi/en/programme/20566

Unesco. (2017) *Education for Sustainable Development Goals: Learning Objectives*. Paris: Unesco, pp. 1–62.

Voulvoulis, N., Giakoumis, T., Hunt, C., Kioupi, V., Petrou, N., Souliotis, I., … Wan Rosely, WIH binti. (2022). Systems thinking as a paradigm shift for sustainability transformation. *Global Environmental Change*, *75*, 102544. https://doi.org/10.1016/j.gloenvcha.2022.102544

Vosniadou, S. (2012). Reframing the classical approach to conceptual change: Preconceptions, misconceptions and synthetic models. In B. J. Frazer, K. Tobin &C. J. McRobbie (Eds.), *Second International Handbook of Science Education. Springer International Handbook of Education* (pp. 119-130). Springer.

Yang, F.-Y. (2005). Student views concerning evidence and the expert in reasoning a socio-scientific issue and personal epistemology. *Educational Studies, 31*(1), 65–84. https://doi.org/10.1080/0305569042000310976

Zangori, L., & Koontz, J. A. (2017). Supporting upper-level undergraduate students in building a systems perspective in a botany course. *Journal of Biological Education*, *51*(4), 399–411. https://doi.org/10.1080/00219266.2016.125750