Pre-schoolers as systems thinkers: Testing the water

● Şebnem Feriver ● Emre Göktepe

Abstract

Systems thinking (ST) is a potential game-changer in terms of helping children and adults to understand the complexity of sustainability, so that they can develop sustainable and just societies in harmony with the planet. In this study, a learning framework was developed for 32 children aged 5-6 and it was implemented over the course of four weeks with children in a pre-school in Turkey. The children were pre- and post-tested with assessment instruments using a mixed method approach. The results revealed a significant development in the ST skills of the children. The children defined system elements related to water more effectively, came to see invisible elements as parts of the system and established high quality causal relations between some of the system elements. In this paper, we provide a summary of the Concept Mapping (CM) findings of this study (for full study, see Feriver, 2021)

Introduction

A growing number of scholars in the field of *Education for Sustainability (EfS)* argue that equipping children to address complexity, which is at the core of systems thinking (ST), will contribute to the goal of sustainable education (Rieckmann, 2012; Bosch & Cavana, 2013; Lewis *et al*, 2014). A system has been described as *'an arrangement of parts or elements that together exhibit behaviour or meaning that the individual constituents do not'* (Dori *et al*, 2020, p.2) and, in this edition of *JES*, Siraj-Blatchford (2022) identifies these behaviours and meanings as 'emergent'.

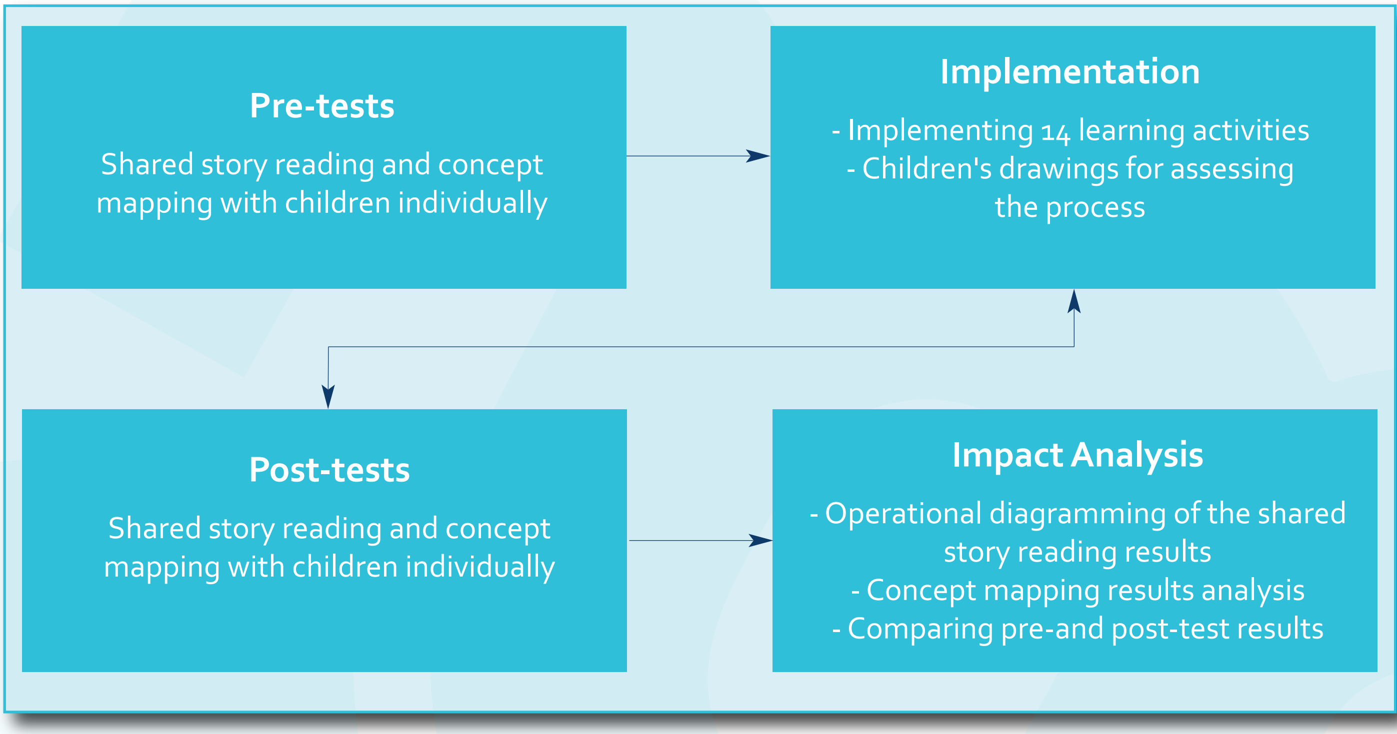
Although the systems approach has been used for more than 50 years, the focus on the primary and early years phases of education is a relatively recent development. Educational research has so far been largely restricted to higher education and workplace studies, which have highlighted the limited ST skills of adults (Jacobson & Wilensky, 2006). Based on the findings of research conducted with adults, ST researchers have suggested that children should be introduced to ST at the earliest age possible (Peppler *et al*, 2020). Indeed, studies with primary school students (e.g. Hokayem & Gotwalz, 2016) and pre-schoolers (Gillmeister, 2017) have demonstrated improvements in the children's ST skills and their progress in the degree and accuracy with which they recognise system elements and the interactions between the elements. Despite these promising results, there is still an important gap in the implementation of systems education for pre-schoolers.

We know that people, especially children (Perkins & Grotzer, 2000), tend to simplify complexities and apply reasoning that assumes a linear causal relationship (Hung, 2008). In the present study, in order to eliminate this tendency, a project-based learning framework with deep learning experiences was developed and implemented, which incorporated sustainability and ST as core components into the pre-schoolers' learning experiences.

Method

The study employed a mixed methods design and the research procedure is summarised in Figure 1. Further details of the overall aims of the study and its methodological and procedural rationale can be found in the full research article published by *Environmental Education Research* (Feriver, 2021). Two assessment tools for Shared Story Reading (SSR) and Concept Mapping (CM) were developed and implemented in the study. The SSR procedures and results have not been dwelt upon in this article in order to focus more closely upon the pedagogic practice and its relevance for practitioners.

Figure 1. Procedure of the study.



The study was conducted following ethical guidelines over four weeks in a small, three-classroom pre-school in a middle-class urban neighbourhood in Ankara, Turkey.

The number of children who took part was 32 ($_{n}$girls = 19, $_{n}$boys = 13, $_{mean}$age = 69 months).

The learning framework provided 14 integrated play-based pre-school learning activities on the theme of 'water' (See Appendix A). These activities were drawn from a guidebook designed to enable children to develop their broad understandings of water (its nature and importance, and interrelated features of its behaviour and use) in the framework of ST principles.

Overall, a comparison of the SSR pre- and post-test results showed that there were notable changes in the children's recognition of system elements and processes. During post-test assessments, invisible elements were added to the children's repertoire, and they established more qualified causal connections between things that change and possible causes of the change.

Concept Mapping (CM)

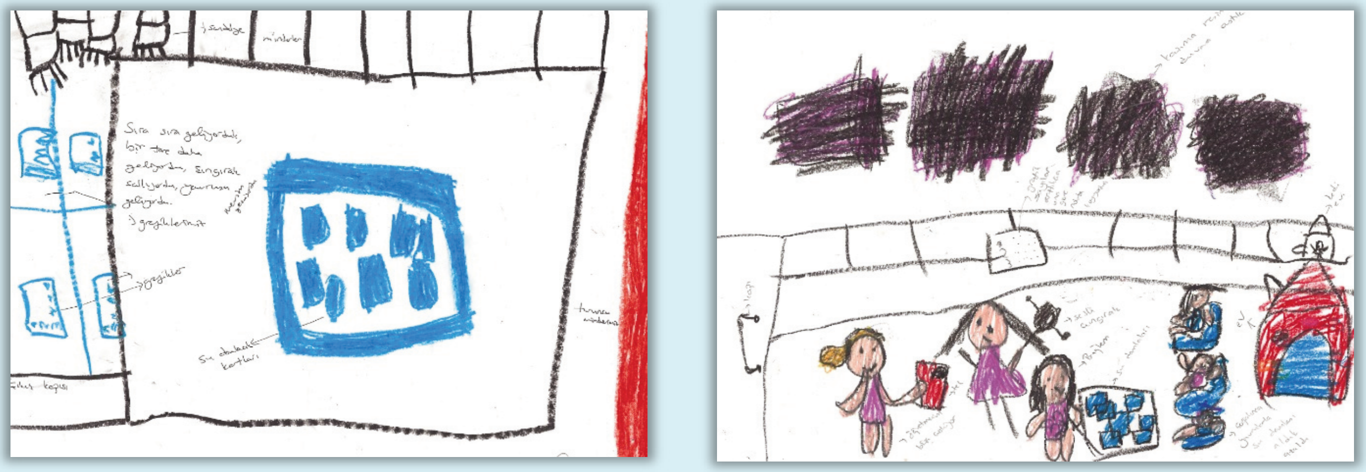
Concept maps may be considered the expression of mental models (Yin *et al*, 2005), and it is an approach that makes it possible to display concepts in a visual and non-linear manner, to address the relations between concepts, and they may be applied in this way to broaden the limits of conceptualisation (Novak & Cañas, 2006). In this study, the CM activity was devised as the second assessment instrument due to its capacity to measure systems thinking ability (Watson *et al*, 2016). A recent study had shown that CM reduces neurocognitive effort and results in better-quality concept generation on sustainability-related issues (Hu *et al*, 2019). CM was also included in the study for the purpose of triangulation, and was implemented, like the SSR, in the form of a pre- and a post-test. CM can be highly-directed, in which case concepts and linking words are provided, or non-directed, when the concepts and linking words are generated by the participants (Ruiz-Primo, 2004). Highly-directed CM has advantages when it comes to validating the accuracy of propositions (Brandstädter, Harms & Großschedl, 2012). The CM in this study was medium-directed, as the children could not be presented with linking words due to literacy limitations and the activities were structured around water and eight different concepts that might be related to water, which were visualised on cards. The set of concepts applied by the children were then identified by four experts and compiled of both obvious and non-obvious concepts related to water. The CM activity was also kept simple in view of the levels of development of the children taking part in the study. Simple concept maps involve fewer components, and they do not aim to create a hierarchy (Ruiz-Primo *et al*, 2001). First, the water card was placed in the middle of a piece of paper and the children were asked which cards might have a relationship with water. As the children placed their chosen cards around the water card, they were asked how the cards were related to one another, to get them to explain the relationship between the concepts on the cards. The links that the children made between the concepts were noted down by the investigator on the piece of paper to elicit links among concepts. The children's reasoning was recorded in the form of CM-linking words. The activities lasted for 10–15 minutes and were videotaped.

Implementation

A typical learning activity (Appendix A, Day 7) inspired by the *Fish Banks Ltd.* game created by Dennis Meadows (co-author of *Limits to Growth in 1972*) involved a structured dramatisation demonstrating the relationship between population growth and water supply, where children acted as antelopes sharing a forest lake. Figure 2 shows the drawings made about the process by two of the children who took part in the learning experience detailed above, together with their narratives about the drawings.

Analysis and results

The CM data was analysed by counting the valid connections constructed by the children. If the connection between two concepts was formulated using a valid proposition, one point was assigned but, if it was formulated using an irrelevant or invalid proposition, no point was assigned. The pre-test and post-test frequencies for each code were calculated in accordance with the standards for inter-coder agreement and content-level comparisons were made (Feriver, 2021). Figure 3 presents the CM interview conducted with Child 14, and it demonstrates how the interviews were visually created.

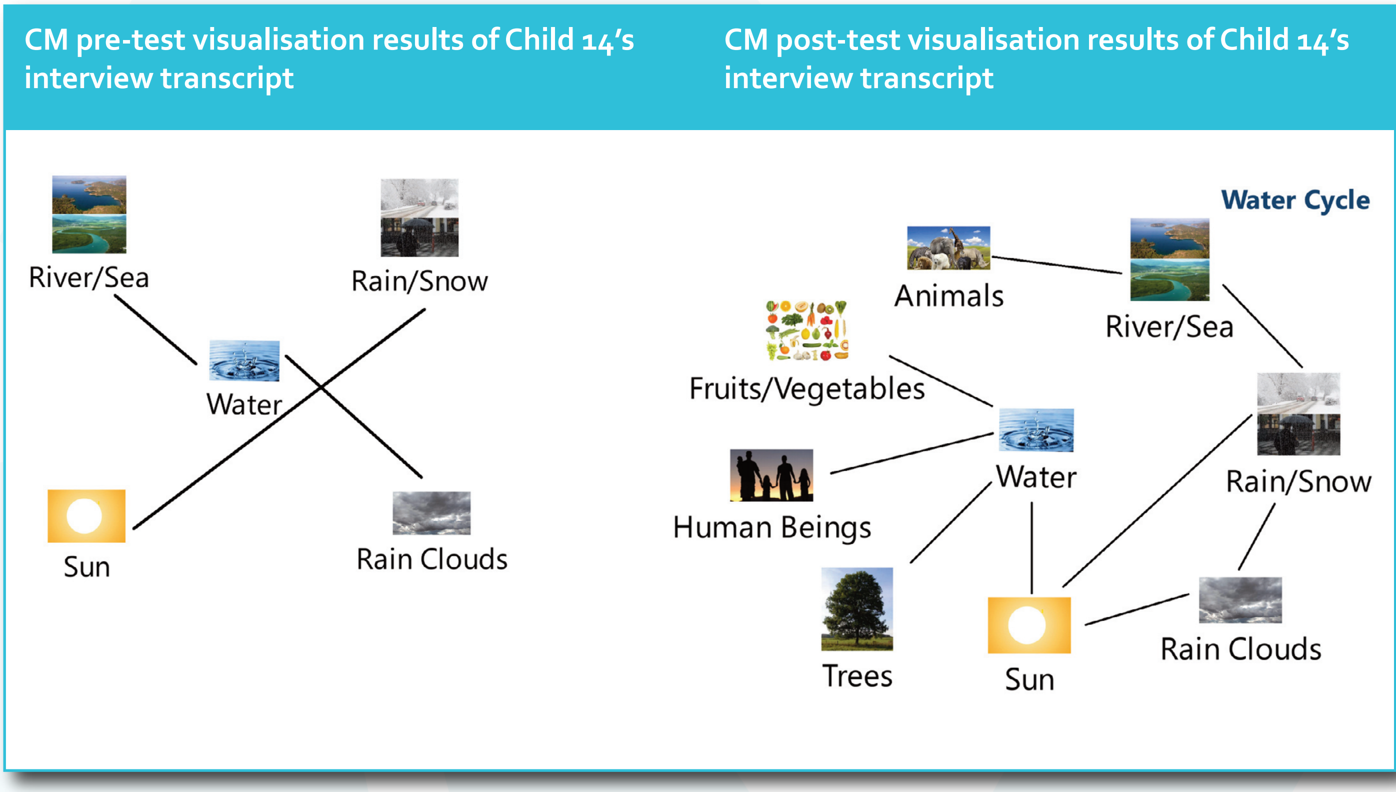


'We were multiplying more and more. With our babies, our numbers were increasing. We showed this on the graph. After a while, our water ran out very quickly. We put this on the graph too. After the water has run out and there is no room left in the forest, the baby and mother antelopes have to migrate somewhere else.'

'When we rang the bell, a season went by, it rained and the antelopes had babies. We put our increased number on the graph. Every season, the baby and mother antelopes took a water card from the lake and we put the reduced number on the graph. After a while we had no water left and we were very crowded in the forest.'

Figure 2. Children's drawings with narratives.

Figure 3. Concept mapping results of Child 14.



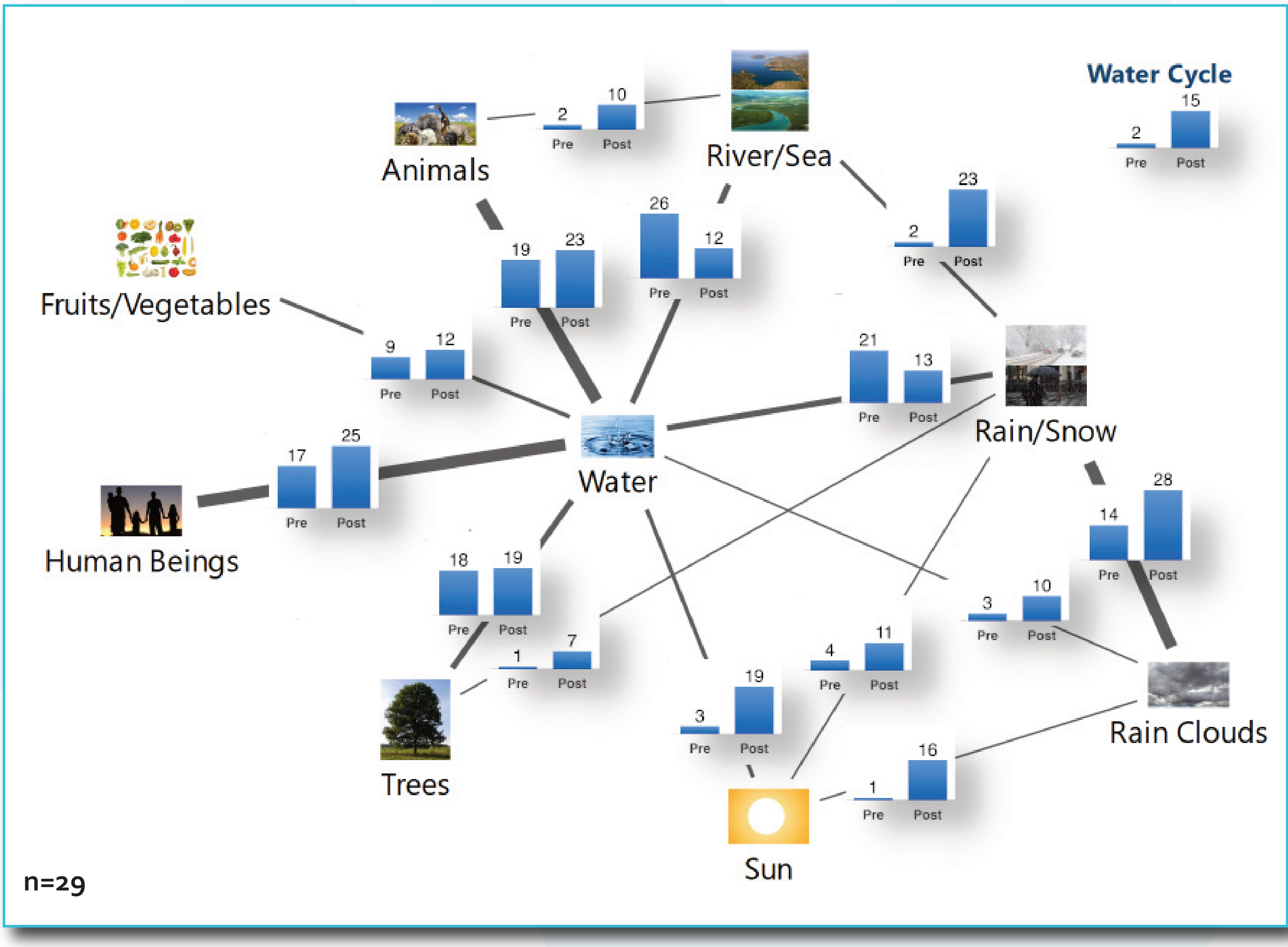


Figure 4. Concept mapping overall results.

For the CM data analysis process, consensus was reached on 16 codes related to the content of the implementation framework. The codes were placed on the concept map as shown in Figure 3, in much the same way as the cards were placed during the child assessment process. The visuals in this figure are, in fact, the cards used in the assessments of the children.

The thickness of the connecting lines in the Figure 4 combined CM (see page 22) reflect the total frequencies obtained from both the CM pre- and post-tests, with the thickest line representing the highest frequency and the thinnest line the lowest. The post-CM analysis process revealed that the children established consecutive connections between the elements *water-sun* (sun evaporates water), *sun-rain cloud* (evaporated water gathers in the rain cloud) and *rain cloud-rain/snow* (rain/snow falls from the rain cloud and, for some children, it rains/snows on the river/sea). The occurrence of this three-stage consecutive connection was coded as the 'water cycle' and the frequencies for this code were presented in the upper right corner of the concept map.

For an overall appreciation of the extent to which the comparison of the CM pre-test and post-test results showed that there were notable changes in the children's recognition of connected elements and processes, and higher occurrence regarding more sophisticated connections, reference should be made to Feriver (2021).

Implications and conclusion

This study has shown that learning experiences that expand children's causal structure development in a complex context, and help them to structure this knowledge holistically, yield positive results.

Further studies are recommended in order to develop the validity and credibility of this approach further. Children are known to create well-structured, coherent and cohesive narratives starting from at least the age of five (Schick & Melzi, 2010). The concept maturity, causal reasoning and narrative abilities displayed by the children in this study at the age of around five suggest that a shift in the focus of systems research towards children in this age group is possible.

Understanding complex systems involves more than recognising elements; it requires reasoning about causal connections (Grotzer *et al*, 2017). This in turn can be supported by mechanism knowledge – i.e. an understanding of the patterns of relationships within which systems work. Expansion of the mechanism repertoire leads to significant achievements in terms of causal complexity (Grotzer, 2012). Like other pieces of research (i.e. Grotzer & Basca, 2003; Perkins & Grotzer, 2000), this study also indicates that learning experiences have the potential to expand children's causal structure development in a complex context.

Another educational implication of this study is that it illustrates the value of educational experiences directed towards deep learning, which widen children's experiences through a project-based approach that aims to extend learning over time. The study shows that children may be engaged in explicit discussions on causality, not only to focus on the visible but also on invisible system elements and mechanisms. As leverage in the course of these processes, asking children high-demand questions, guiding them to develop a more complex explicit understanding by drawing out their implicit understandings, and helping them to understand 'why' by linking direct experience and vocabulary to learning, have the potential to create the systems thinkers needed by our planet (Spratling, 2015). In order to provide these opportunities, there is a crucial need to improve the capacities of teachers for ST and EfS, as their capacity has the potential to positively affect sustainability competences of their students (Murphy *et al*, 2021).

During early childhood, children are known to face certain constraints in their expressive language development (Kuhn *et al*, 2016). This study has shown that CM can be useful for grasping the implicit understandings of children and supporting them in creating narratives with the help of visual images. In the CM exercise, the children were observed to be able to create links between the systems elements more easily and more frequently, and even to develop a consecutive narrative in such a way as to form a cycle.

Research has shown that humankind has limitations in terms of demonstrating ST skills (e.g. Cox *et al*, 2019). As a matter of fact, what we have done to our planet is the most obvious proof of these limitations. ST is not a perspective that will come to the fore unless we intervene deeply in the mental models that we use to make sense of the world. It is therefore essential for the wellbeing of our planet that we integrate with this discipline at an early age and allow it to guide us in forming our mental models. Based on these premises, this study was intended to pioneer the development of an integrated approach to the curriculum and assessment that incorporates ST with Education for Sustainability, using the theme of 'water', and so to offer inspiration to education policy makers, researchers and educators.

References

Bosch, O. & Cavana, R.Y. (2013) 'Special issue: Systems education for a sustainable planet', *Systems*, (1), 27–28

Brandstädter, K., Harms, U. and Großschedl. J. (2012) 'Assessing System Thinking through Different Concept-Mapping Practices', *International Journal of Science Education*, **34,** (14), 2147–2170. doi:10.1080/09500693.2012.716549

Cox, M., Elen, J. & Steegen, A. (2019) 'Systems thinking in geography: can high school students do it?', *International Research in Geographical and Environmental Education*, **28,** (1), 37–52

Dori, D., Sillitto, H., Griego, R.M., McKinney, D., Arnold, E.P., Godfrey, P., Martin, J., Jackson, S. & Krob, D. (2020) 'System definition, system worldviews, and systemness characteristics', *IEEE Systems Journal*, **14,** (2), 1538–1548

Feriver, Ş. (2021) 'Pre-schoolers as systems thinkers: testing the water', *Environmental Education Research*, **28,** (3), 430–456

Gillmeister, K.M. (2017) *Development of early conceptions in systems thinking in an environmental context: An exploratory study of preschool students' understanding of stocks & flows, behavior over time and feedback* (Doctoral dissertation). State University of New York, New York, USA

Grotzer, T.A. (2012) *Learning causality in a complex world: Understandings of consequence.* Lanham, MD: Rowman & Littlefield

Grotzer, T.A. & Basca, B.B. (2003) 'How does grasping the underlying causal structures of ecosystems impact students' understanding?', *Journal of Biological Education*, **38,** (1), 16–29

Grotzer, T.A., Solis, S.L., Tutwiler, M.S. & Cuzzolino, M.P. (2017) 'A study of students' reasoning about probabilistic causality: Implications for understanding complex systems and for instructional design', *Instructional Science*, **45**, (1), 25–52

Hokayem, H. & Gotwals, A.W. (2016) 'Early elementary students' understanding of complex ecosystems: A learning progression approach', *Journal of Research in Science Teaching*, **53**, (10), 1524–1545

Hu, M., Shealy, T., Grohs, J. & Panneton, R. (2019) 'Empirical evidence that concept mapping reduces neurocognitive effort during concept generation for sustainability', *Journal of Cleaner Production*, (238), 1-12

Hung, W. (2008) 'Enhancing systems-thinking skills with modelling', *British Journal of Educational Technology*, **39,** (6), 1099–1120

Jacobson, M.J. & Wilensky, U. (2006) 'Complex systems in education: Scientific and educational importance and implications for the learning sciences', *Journal of Learning Sciences*, **15**, (1), 11–34

Kuhn, L.J., Willoughby, M.T., Vernon-Feagans, L., Blair, C.B. & Family Life Project Key Investigators (2016) 'The contribution of children's time-specific and longitudinal expressive language skills on developmental trajectories of executive function', *Journal of Experimental Child Psychology*, (148), 20–34

Lewis, E., Mansfield, C. & Baudains, C. (2014) 'Ten tonne plan: Education for sustainability from a whole systems thinking perspective', *Applied Environmental Education & Communication*, **13**, (2), 128–141

Meadows, D., Meadows, D. & Randers, J. (1972) *The Limits to Growth; A Report for the Club of Rome's Project on the Predicament of Mankind.* https://archive.org/details/limitstogrowthroomead New York: Universe Books

Meadows, D. (n.d.) *The Fish Banks Ltd. game.* Retrieved from: https://systemdynamics.org/products/fish-banks-game/

Murphy, C., Mallon, B., Smith, G., Kelly, O., Pitsia, V. & Sainz, G.M. (2021) 'The influence of a teachers' professional development programme on primary school pupils' understanding of and attitudes towards sustainability', *Environmental Education Research*, **27,** (7), 1011–1036

Novak, J.D., & Cañas, A.J. (2006) *The theory underlying concept maps and how to construct them.* Technical Report IHMC CmapTools 2006-01. Pensecola, FL: Institute for Human and Machine Cognition

Peppler, K., Thompson, N., Danish, J., Moczek, A. & Corrigan, S. (2020) 'Comparing first and third person perspectives in early elementary learning of honeybee systems', *Instructional Science*, (48), 291–312

Perkins, D.N. & Grotzer, T.A. (2000) *Models and moves: Focusing on dimensions of causal complexity to achieve deeper scientific understanding.* Retrieved from: https://eric.ed.gov/?id¼ED441698

Rieckmann, M. (2012) 'Future-oriented higher education: which key competencies should be fostered through university teaching and learning?' *Futures*, **44,** (2), 127–135

Ruiz-Primo, M.A., Schultz, S.E., Li, M. & Shavelson, R.J. (2001) 'Comparison of the reliability and validity of scores from two concept-mapping techniques', *Journal of Research in Science Teaching*, **38**, (2), 260–278

Schick, A. & Melzi, G. (2010) 'The development of children's oral narratives across contexts', *Early Education & Development*, (21), 293–317

Siraj-Blatchford. J. (2022) 'Emergent science education for sustainability', *Journal of Emergent Science*, (23) (this edition)

Spratling, C. (2015) *Promoting early concept development through adapted books.* Presented at International CHARGE Syndrome Conference, Chicago, U.S.A.

Watson, M.K., Pelkey, J., Noyes, C.R. & Rodgers, M.O. (2016) 'Assessing conceptual knowledge using three concept map scoring methods', *Journal of Engineering Education*, **105**, (1), 118–146

Yin, Y., Vanides, J., Ruiz-Primo, M.A., Ayala, C.C. & Shavelson, R.J. (2005) 'Comparison of two concept-mapping techniques: Implications for scoring, interpretation, and use', *Journal of Research in Science Teaching*, **42**, (2), 166–184

Şebnem Feriver, Systems Thinking Association in Turkey.
E-mail: sebnemferiver@gmail.com

Emre Göktepe, Systems Thinking Association in Turkey.
E-mail: bilgi@egitimdesistemdusuncesi.org

Appendix A

Flow	Learning Activities	Learning Outcomes
Day 1	Warm-up activity: Introducing the Water-Drop hand puppet to children	Exploring children's knowledge of water
Day 2	Interactive storytelling activity: *'Could a Dinosaur Have Drunk from the Same Water?'* Creation of a water web	Understanding that water does not disappear in its cycle Discovering that water use creates webs
Day 3	Science activity on the three states of water Preparation of water bags to observe evaporation, condensation and precipitation	Understanding that water is in a permanent cyclic system in three states Exploring the stages of the water cycle
Day 4	Short animated video about the water cycle and water resources Play activity describing the interconnections among water resources	Discovering different water resources on Earth Recognising that different water resources on Earth feed into each other in a connected system
Day 5	Art activity: Individual drawing activity displaying learning about water resources	Describing the learning experience by individual drawing and verbal expression
Day 6	Water Talks: Why is the Earth called the Blue Planet? Science activity on limits to accessing fresh water	Recognising that while the Earth contains plenty of water, freshwater is a very limited natural resource Exploring adverse impacts of excessive consumption of fresh water resources on people, animals and plants
Day 7	Play activity demonstrating limits to growth with limited water resources and a growing population	Discovering the causal relationship between population growth and fresh water resources Understanding exponential growth conceptually
Day 8	A short movie on Africa's great Serengeti wildebeest migration Illustration of different animals' migration cycles	Discovering the migration cycles of different animals Understanding the causal relationship between animal migration and water
Day 9	A drama activity representing animals looking for food and water in a cyclical pattern	Recognising that some animals also migrate in a cyclical pattern to survive
Day 10	Art activity: Individual drawing activity displaying learning about water Photo exhibition summarising the learning experiences of children	Describing the learning experience by individual drawing and verbal expression Summarising the learning experience by browsing and discussing the activity photo exhibition
Day 11	Book exploration activity	Exploring different stories told about water
Day 12	Drama activity representing exponential growth in terms of water contamination	Exploring how water pollution can be transmitted rapidly to different sources within the connected system
Day 13	Interactive storytelling activity: *Where is the Starfish?*	Understanding the causality between water pollution and the loss of biodiversity in marine ecosystems Creating a behaviour over time graph about marine pollution
Day 14	Bar graph drawing activity to demonstrate hidden water use for products such as jeans, bars of chocolate and water bottles	Exploring the concept of 'hidden water usage' by understanding that the production of food/goods also requires water consumption Recognising the relations between water consumption and our daily consumption habits Creating a bar graph demonstrating hidden water consumption

Table 1. Implementation of the learning framework.