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The repertory grid as a tool for evaluating the development of students' ecological system thinking abilities

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ABSTRACT

Comprehension of complex systems is essential for in-depth understanding of environmental issues. This study assessed the impact of a place-based ecological learning unit on development of junior high school students' systems thinking skills. It implemented, in a paired pretest–posttest design with 20 students, a qualitative approach using the Repertory Grid-Technique. Qualitative data analysis used the Systems Thinking Hierarchy (STH)-model.

Data indicate that most of the students advanced to a higher level within the STH-hierarchy, and developed the ability to generalize ecological phenomena.

Findings support that in relation to system thinking, the repertory grid is an effective tool for assessing learners' conceptual models and they broaden the implementation of RG as a research tool to the context of ecological complexity.

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Introduction

Biodiversity issues are recognized as one of the major components of the global environmental crisis (Intergovernmental Panel on Biodiversity and Ecosystem Services, 2013). The Millennium Ecosystem Assessment clearly outlines the dependence of human well-being on ecosystem services derived from Earth's biodiversity (Millenium Ecosystem Assessment, 2005). In response to the importance of drawing humanity's attention to the ongoing biodiversity crisis, 2010 was pronounced by the UN 'Year of Biodiversity'.

The role of education in addressing the challenges of biodiversity is undisputed (Millenium Ecosystem Assessment, 2005). While biodiversity has become a part of the curriculum from pre-school throughout secondary school (K-12), it is often addressed from a narrow perspective, focusing primarily on anthropogenic influences, with the aim of developing the environmental awareness and responsible behavior necessary for sustaining biodiversity (UNESCO, 1993; World Resource Institute, The World Conservation Union/United Nations Environmental Program, 1992). There is accumulating evidence that comprehension of complex systems is essential for in-depth understanding of environmental issues, such as those related to human impact on biodiversity and the behavioral changes required at the individual and societal level (Eilam, 2012). In-depth understanding of ecosystem function – the mechanisms which are the essence of the self-organization of ecosystems and render them sustainable systems – is a crucial component for the comprehension of biodiversity issues (Hmelo-Silver et al., 2008; Nguyen & Bosch, 2013). Comprehension of the structural and behavioral aspects of complex systems is a challenging cognitive endeavor for science students (Jacobson & Wilensky, 2006). Ecosystems are inherently characterized by their complexity, and studies with learners have demonstrated a wide range of difficulties in their understanding of concepts and ideas that are attributed to the ecosystem properties (Booth Sweeney & Sterman, 2007; Eilam, 2002). Place-Based Education, by integrating the local physical environment, community and authentic environmental challenges, may provide a meaningful environmental educational framework to achieve this goal (Endreny, 2010; Glasson, Frykholm, Mhango, & Phiri, 2006).

The aim of this study was to investigate the influence of a place-based environmental learning unit that implements the earth system approach (Orion & Ault, 2007) on development of junior high school pupils' systems thinking skills in the context of ecology, as this is reflected in their advancement to higher levels within the System Thinking Hierarchy (STH) model (Ben-Zvi Assaraf & Orion, 2005). To this end, this study implemented the

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Repertory Grid tool to evaluate system thinking abilities. While this tool has been previously used for evaluating learners' system thinking in other contexts (Ben-Zvi Assaraf & Orion, 2005, 2010a,b), the present study broadens this to the context of ecology.

Theoretical framework

Developing system thinking as a challenge for Science and Environmental Education

Fostering an environmentally literate citizenry is a major key to achieving sustainability. The Tbilisi Declaration (UNESCO-UNEP, 1978) – one of the seminal documents in environmental education (EE) – defined ‘‘a basic understanding of the environment’’ as a component of the knowledge objective of EE. With respect to curriculum development in EE, Hungerford, Peyton, and Wilke (1980) synthesized a set of hierarchical target levels. The first target level is the *Ecological Foundations Level*, which aims to provide sufficient ecological foundations knowledge, and thus enable individuals to make ecologically sound decisions with respect to environmental issues. This target level states that learners should be able to apply major ecological concepts to the analysis of environmental issues, and predict the consequences of proposed solutions to environmental issues using their knowledge of ecological concepts. Roth, who coined the term Environmental Literacy, includes the understanding of a number of ecological processes (for example: population dynamics, interactions and interdependence, energy transfers, biogeochemical cycling, succession, thinking in terms of systems, thinking in terms of time frames and scales) as crucial components of the knowledge strand of the Functionally Environmentally Literate individual (Roth, 1992). The above examples of keystone literature in the field of EE support the claim that an understanding of ecosystem structure and function is a fundamental component in the developing of the environmental literacy required to understand complex multidimensional environmental issues and make responsible behavioral choices. Current guidelines for excellence in EE (NAAEE, 2010) explicitly state system thinking as one of its underpinnings.

Sauvé (2005) identified the ‘systemic current’ as one orientation in the pedagogical ‘‘landscape’’ of EE, according to which systemic analysis is indispensable to the recognition and understanding of environmental realities and problems. Systemic analysis, according to this typology, includes the relations among biophysical and social elements. This approach to environmental realities is cognitive by nature and its perspective is of enlightened decision. A pedagogical example of this approach is that of Keiny and Shachack (1987) in the context of outdoor ecology study: a field trip in an arid environment, for example, enables direct observation, in situ, of a concrete environmental reality or phenomenon, and the analysis of its component parts and relations, in order to develop a systemic model leading to a global understanding of the related issue in the arid climate. They argue that the development of a systemic model of the related issues enables the learners to identify and select more enlightened solutions.

In light of increased recognition of the importance of an understanding of ecosystems, the literature suggests that comprehension of the structural and behavioral aspects of complex systems has become a challenging cognitive endeavor for science students (Jacobson & Wilensky, 2006). Research has unveiled many difficulties that students of all ages face when dealing with complex systems (Ben-Zvi Assaraf & Orion, 2005; Hmelo-Silver & Pfeffer, 2004; Plate, 2010). For example, students have difficulty developing a coherent and comprehensive perception of the structure and multi-variable web of relationships (Jacobson, 2001) that exist in systems. Other difficulties result from the fact that complex systems are characterized by multilevel organization, interconnections, heterogeneous components, and invisible dynamic processes (Ferrari & Chi, 1998; Hmelo-Silver & Azevedo, 2006; Wilensky & Resnick, 1999). Learners have difficulty understanding multiple levels and making connections between them (Duncan & Reiser, 2007). This derives from the fact that relationships across different levels of such systems are often implicit, with indirect causality (Hmelo-Silver & Azevedo, 2006; Jacobson, 2001), and therefore the relationships among the various system agents are not intuitively obvious (Duncan & Reiser, 2007). Such characteristics present cognitive barriers that make complex systems difficult to understand (Feltovich, Coulson, & Spiro, 2001). Another characteristic of systems is ‘emergence’ (Jacobson & Wilensky, 2006): The unpredictable and non-intuitive macroscopic-level expression of a system's self-organization, resulting from the processes occurring within its subsystems, shows emergent and complex properties not exhibited by the individual components. Students, however, tend to believe there is a linear relationship between the salience of a phenomenon and its corresponding effect, and ignore the fact that in complex systems, a non-salient phenomenon may contribute a significant influence (Hmelo-Silver & Pfeffer, 2004; Jacobson, 2001; Kaneko & Tsuda, 2001).

What are the implications of comprehending complex systems in the context of ecology? Ecosystems are inherently characterized by their complexity, and studies with learners have demonstrated a wide range of difficulties in their understanding of concepts and ideas that are attributed to the ecosystem properties. For example, some studies report about learners' misconceptions related to food web, ecological adaptation, carrying capacity, feedback cycles, and ecosystem and niche concepts (Booth Sweeney & Sterman, 2007; Eilam, 2002; Munson, 1994). Studies addressing pupils from the elementary to the high school level report that pupils do not see ecosystem function as an interrelated whole. For example, photosynthesis, respiration and decay are not related to cycling of matter in ecosystems (Leach, Driver, Scott, & Wood-Robinson, 1996). Furthermore, when describing relationships in nature, children tend to use simple linear causality, in which only one population directly affects another, rather than several different pathways forming a food web (Booth Sweeney & Sterman, 2007; Dor-Haim, Amir, & Dodick, 2012; Grotzer & Bell-Basca, 2003). In view of this, Grotzer and Bell-Basca (2003) point out that there is a need to provide students with structural knowledge that refers 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). Perkins and Grotzer (2005) claim that understanding and reasoning effectively about ecosystems involves comprehending a variety of causal patterns in nature, for instance domino like, cyclic, or reciprocal patterns between organisms, as well as between organisms and abiotic components. Without a grasp of the behavior of such patterns, students are likely to impose a simple linear form to organize new information. Along this line, more recently, Eilam (2012), based on her study of system thinking and feeding relations among junior high school pupils, identified the following interrelated deficiencies: (a) feeding relations are perceived in a linear rather than a web configuration; (b) understanding of webs was also constrained by deficiencies in temporal and spatial thinking; (c) causality and implicit interactions were not evident, thus strengthening the students' perception of distinct components rather than whole systems. Eilam (2012) concluded that ‘‘Such linear and unidirectional views and temporal and spatial thinking deficits also impeded students' ability to understand that matter and energy cycles are an inherent part of the larger biosphere system and at the same time partly occur within and interact with the biotic organisms involved in the feeding web subsystem’’ (p. 232).

Another aspect of systemic thinking was addressed by Magntorn and Helldén (2007) in their study of Swedish secondary school students' ability to generalize the knowledge of ecosystems:

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