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EDITED BY
Ebba S. I. Ossiannilsson,
Swedish Association for Open, Flexible and Distance Education (SADE), Sweden

REVIEWED BY
Dragan Komljenovic,
Hydro-Québec's Research Institute (IREQ), Canada

*CORRESPONDENCE
Rebecca C. Jordan
✉ jordanre@msu.edu

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Systems thinking tools to address SDG #4

Rebecca C. Jordan*, Steven A. Gray and Amanda E. Sorensen

Department of Community Sustainability, College of Agriculture and Natural Resources, Michigan State University, East Lansing, MI, United States

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Introduction

Sustainable Development Goal (SDG) #4 is titled "Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all" [United Nations Educational, Scientific and Cultural, Organization (UNESCO), 2014]. As described in the 10 target areas and 11 indicators, this goal is focused on increasing fair and just participation in high quality education including experiences in higher education. While the targets and indicators speak for themselves, underpinning the entire goal is the notion that reducing the vast inequity in education across all nations will result in inclusive decision-making, reduced poverty, and engaged citizenship. In combination with the other SDGs, this increase in just participation will result in greater sustainable development and global engagement. Further safe access to effective programs and qualified individuals is warranted. The goal of this opinion piece is to suggest a cost-effective means to provide quality sustainability education, which focuses on systems thinking; the latter of which we see as a conduit to literacy and numeracy as listed in SDG #4.

More specifically, we suggest, as have many others (Williams et al., 2017) that systems thinking is not only a core sustainability competency but also is a conduit for engagement in lifelong learning. Below, we define systems thinking as a competency, relate it to both literacy and numeracy and suggest an assessment approach. We argue that this approach is an excellent way to encourage decision-making strategy and the means to reduce complexity; both of which are essential to sustainable development.

Defining systems thinking

Systems thinking is often cited as the foundation of sustainability science curricula (e.g., Gray et al., 2019). While there are many descriptions of systems thinking for sustainability (Wiek et al., 2011; Phelan et al., 2015; Wei et al., 2015), we follow Gray et al. (2019), who define critical dimensions of systems thinking to include: (1) system structure, (2) identification of leverage points and mechanism for change, (3) system function, and (4) trade-off analysis. This approach requires the learner to identify specific dynamics and relationships between structure and mechanisms in a system and, to analyze these dynamics and relationships as overall system function.

Before defining systems thinking, however, we fit our perspective into a broader view of systems or complexity theory. Braithwaite et al. (2018), provide a review of fundamental ideas from life and social sciences. In doing so, these authors make a distinction between interdependent and interacting components with fuzzy boundaries and non-linear outcomes that are characterized by varying levels of uncertainty. Further, these ideas stress the highly dynamic nature of these systems as mechanisms interact at different scales of organization.

Case studies of such complex systems ranging from micro to macro scales of human organization demonstrate the need for tools that enable systemic understanding (e.g., Bar-Yam, 2002). Traditionally, individuals have studied distinct parts of systems and measured the relatively certain links between these parts (Sturmberg, 2009). While doing so works well for simple systems, complex systems such as those characterized by human-environment interactions, are much more difficult to study because there are many more possibly confounding variables interacting across different layers of organization. Braithwaite et al. (2017) therefore argue that the nature of independent agents acting adaptively and having the capacity for self-organization and subsequent evolution requires a different epistemology of study. These authors highlight feedback loops, emergent properties, and uncertainty as core principles of study. We agree and frame our ideas in similar but distinct categories as defined below.

Because social and ecological well-being depend on each other, competency in systems thinking can enable learners to develop better ways to reason about likely outcomes in sustainable systems. In this way, learners are developing numeracy skills. Another major benefit of fostering systems thinking is that learners can play a role in facilitating reasoning across social and environmental systems, which is critical in global environmental issue engagement.

Such systems thinking competency can contribute to learner engagement with sustainability-focused issues; the latter of which necessitates evoking literacy skills. In addition, if learners think critically about the complex system dynamics, they are better prepared to predict system behavior and to engineer favored outcomes (see identifying "leverage points" discussed by Meadows, 2008). Furthermore, learners can evaluate trade-offs between different plausible decisions to be made regarding system outcome.

Recent years have brought about a fair bit of research on systems thinking in sustainability education (see review in Williams et al., 2017). Similar to Gray et al. (2019), systems thinking is necessarily transdisciplinary (Williams et al., 2017). Further, data support the notion that once key habits of thinking are mastered, regardless of the context, learners tend toward more sophisticated thinking when new contexts are encountered (Mambrey et al., 2020). When it comes to assessment of this type of thinking, there is a gap in terms of how we measure both technical and contextual aspects of systems thinking (Dugan et al., 2022).

Similar to that as defined above from Mulvaney et al. (2014) and Gray et al. (2019) also published a case study focused on measuring learner ideas around system pieces, function, and leverage points that are able to be manipulated. Gray et al. (2019), however, used a standardized modeling approach designed by one of the authors to engage students in cognitive mapping. Cognitive maps are external representations of individual "mental models" about complex systems (Jones et al., 2011). While cognitive maps have been used to study students' learning about complex biological systems, e.g., Dauer et al. (2013) gene-to-evolution maps, such tools have required lengthy assessments and are time intensive to study.

Case study of teaching social-ecological (systems) thinking

We recommend, however, using the framework described above and a mental modeling tool, which was designed to engage with complex system thinking to not only involve students in learning about complex systems but also to assess and further tailor sustainability learning systems. In Gray et al. (2019), students in an introductory sustainability science class at a large mid-western United States ($N = 40$) research university were engaged in learning about specific cases studies. These students were a mix of science and non-science majors. These authors used the four tenets of systems thinking that are described above and found that students ranged across each. As an external metric, these authors asked experts to rate student models as high, medium, or low in systems thinking. Those who were ranked more highly in systems thinking had models associated with more concepts and connections between concepts but had lower levels of the ratio of number of connections/number of concepts. Further, the authors found that certain concepts were more present in higher systems thinking type models. This finding suggests that certain ideas were held in common by different levels of systems thinking and that patterns could be typified, which can help instructors to guide future learning experiences.

The modeling tool, reference above, is called mental modeler (e.g., www.mentalmodeler.org; an online Fuzzy Cognitive Mapping tool) (Gray et al., 2013) and is an easy-to-use qualitative cognitive mapping software suite based on a semi-quantitative cognitive mapping technique called fuzzy cognitive mapping. Here the system map is weighted, and the nodes of the graph qualitatively represent the components of the system and the edges between the nodes quantitatively represent the direction and strength of suspected causal relationships between components. In contrast to fully qualitative cognitive maps, this technique allows for the representation of dynamic and inter-related system activity where students can model in discrete time steps to test model outcome scenarios. Yet unlike fully quantitative maps, this technique is easy to grasp by most and they tend to do so quickly. In this manner, the mental modeler tool allows for simultaneous assessment of structure and function and the ways that students represent mechanism across scales. This type of assessment is particularly ideal for systems thinking. Finally, the tool allows students to write out ideas as a parallel mode of representing ideas.

This modeling tool is ideally matched to the goal of students developing systems thinking fluency and allowing them to mitigate and potentially solve complex system related problems in the future. Such learners need to develop creative solutions based on deep understanding of the system and then propose novel actions related to policy intervention and other type of sustainability related activity. With this, students can engage in dialogue about system dynamics and sustainability related problem-solving. With focus on SDG #4, there is rarely a single correct answer to sustainability problems and management actions taken can impact different stakeholders differently and can cause unintended consequences. Systems can be managed for multiple outcomes but with respect to sustainability there should be minimal negative impacts on humans and the environment. Such management should focus on minimal adverse tradeoffs and allow the students to determine plausible broader impacts of potential decisions on sustainable outcomes.

Conclusion

The Secretary-General of the United Nations provides an annual report evaluating the progress toward the Sustainable Development Goals [United Nations Educational, Scientific and Cultural, Organization (UNESCO), 2014]. Various sustainability monitoring efforts are used to measure progress in the ten target areas. A number of these reports have been published and one element remains clear: there simply are not enough tools and data to determine the extent to which targets are being hit. Yet, given the value placed on equity, it is likely there are major disparities among communities and nations. In this opinion piece, we suggest focusing on key assessment dimensions and using low-cost available technology may enable a wider reach for measurement tools. Further the use of common dimensions will enable a certain level of data standardization.

In summary, we suggest that cognitive maps, and possibly scenario outputs, paired with these four dimensions: (1) system structure, (2) identification of leverage points and mechanism for change, (3) system function, and (4) trade-off analysis can be used to measure systems thinking and systems thinking as a broad envelope can be used to target skills focused on literacy and numeracy. For example, instructors can evaluate whether: Can students evaluate the range of direct and indirect outcomes and explain what nodes are linked to each change? Are all unknowns represented in the cognitive map? Are there specific trade-offs? and Which stakeholders are likely to invest in strategies represented by each trade-off? Among other important complex system questions. We suggest that these tools and simple questions can go a long way to engaging learners in deeply rooted sustainability related problem-solving. The latter, of which, is essential if we are to meet future regional, national, and international goals for sustainable cities.

Author contributions

RJ conceived and wrote the initial draft of this article. AS fully edited and added sections to the article. SG wrote and provided the case study (co-authored by RJ). All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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