Review on education for sustainable development: system thinking for sustainable chemistry education curriculum

A S Shidiq*, A Permanasari and Hernani
Science Education Department, Postgraduate School, Universitas Pendidikan Indonesia, Jl. Dr. Setia Budi No. 229, Bandung 40154, Indonesia

*corresponding author: asyahidul@gmail.com

Abstract. Education must be able to connect technology advances, the industry and learning in the classroom. These include advances in the fields of chemistry and chemical education to teach students to be able to contribute to solving problems and sustainable development in the future. Chemical education has the main role in education for sustainable development. For this reason, we need a concept in a chemical education curriculum that can support sustainability. System thinking in chemistry education is relevant to sustainability. Through system thinking, students are challenged to holistically understand the scientific process. This study aims to review the literature on systems thinking and sustainability in chemical education. A total of 9 articles from reputed international journals were the main sources for review. The results of the literature study conducted were the implementation of the system thinking in a chemical education curriculum was a potential thing. The relationship between sustainability and systems thinking were discussed.

1. Introduction
The development of information, technology and digitalization in the era of 4th Industrial Revolution led to changes in education towards 21st century teaching and learning [1–3]. Education must be able to connect technological advances, the industry and learning in the classroom, including advances in the fields of chemistry and chemical education. These include advances in the fields of chemistry and chemical education to teach students to be able to contribute to solving problems and sustainable development in the future in accordance with the concept of Education for Sustainable Development [4–8].

Many terms are used for Education for Sustainable Development, such as Sustainable Education, also called Sustainability Education and formerly Environmental Education. All of these terms lead to the goal of helping students develop knowledge, skills, values, necessary abilities and dispositions to respond to complex socio-economic problems in the 21st century [6].

There is a great need in education for sustainable development in the world. Teacher education has an important role in promoting a sustainable future. Teaching is needed so that education about sustainable development becomes systematic [4, 7]. The teacher has a long-term influence on this sustainable development. However, teachers usually have a lack of knowledge and skills in sustainable development [9]. Therefore, the education curriculum that leads to sustainability is needed.

Chemical education has the main role in education for sustainable development as the chemical industry does [8]. There are multiple chemical-based products in everyday life. Therefore, chemistry education must emphasize the understanding of students on the role of chemistry in society and
enhance their ability to assess products related to chemistry like the effect of chemistry for the future, its contribution to sustainable society and assist in the appropriate use of natural resources [8, 10]. Skills for analyzing complex things in various domains such as society, environment, and economy, at various scales, so that considering the effects of causation and other systemic features are called systems thinking skills [11]. Therefore, thinking of system is the key competency to promote sustainable development.

System thinking in chemical education is pertinent to scientific method understanding and the achievement of holistic understanding of chemical-related problems. Through system thinking, students are challenged to comprehend the scientific process of a problem method, data and conclusion holistically [12]. In addition, system thinking is important in looking at issues from a different perspective. People who understand chemistry need to use their chemical understanding in decision making, social problems related to chemistry and to understand how innovation in chemistry can influence sociological processes [13].

We can achieve the system thinking perspective on chemical education by looking into environmental and socio-economic factors. In addition, certain cases may be related to local and international problems, so that it requires system thinking on a global scale. Thus, interdisciplinary thinking in a holistic manner and understanding causality is an essential prerequisite for the engagement in sustainability issues and as part of system thinking [12, 14]. Therefore system thinking is an approach and skills needed for a sustainable chemical education curriculum.

The system thinking and sustainability in chemical education are being studied by experts in chemical education. Some of the research that has been done is a study of a sustainable chemical education model in the future that puts system thinking skills as the main skills students need to have [12, 15–17], research on challenges, opportunities and pedagogical models of chemical education for sustainability [4, 7–10], and the latest research in 2019 on system thinking approaches and skills in the chemistry education curriculum [18–22].

The development of research and publications about system thinking and sustainability in chemical education indicates that the topic has become a concern for chemistry education researchers to overcome the challenges and problems in the 21st century. Therefore, this study aims to review the publications about system thinking and their relevance to sustainability in chemical education.

2. Methods
This study aims to review the academic literature on system thinking and sustainability in chemical education. Nine articles were reviewed in this study. The review was intended to summarize what chemistry education researchers have done and made it easier for practitioners and other researchers to obtain information about system thinking for the chemistry education sustainability curriculum. In addition to 9 articles reviewed, various sources that are relevant and support the topic of systems thinking and sustainability are also used. As a guide to the review conducted, two problem statements were used in this study, namely 1) what is the concept of education for sustainable development in chemistry education?; and 2) what is the concept of the system of thinking for sustainable chemistry education curriculum?

3. Result and Discussion
3.1 The concept of education for sustainable development in chemistry education
Besides the specific chemical skills and knowledge, the extensive perspective of education in the chemistry classroom can be an opportunity for general skill development. This corresponds with education through chemistry [23], including the acquisition of the shift from chemical learning as the knowledge body to enhancing educational skills through chemical subjects. Thus, the realization of Education for Sustainable Development (ESD) in chemistry classes does not necessarily involve specific problems of chemical sustainability. Regardless teaching chemistry topics, teachers can emphasize instructional approaches promoting the respect and responsibility development among
students and assist the students’ need of competency development in their daily lives and as adults in a sustainable world [12, 23–25].

Burmeister [8] has presented four strategies for applying sustainable development issues in chemical education. He suggested that there are strategies to be applied in combination to best include ESD in chemical education as follows: (1) adopting the principles of green chemistry in the laboratory, (2) adding sustainability strategies content in chemical education, (3) including the issues and controversy of socio-science in teaching and (4) using chemical education as part of the development of ESD-based schools.

Burmeister’s approach [8] inspired Jegstad’s work [12] who modifies and expands ESD teaching strategies in chemistry education. Through a model of five ellipses, Jegstad visualizes a model for ESD planning in chemical education. The ellipses constitute five different categories of ESD, namely knowledge of chemical content, contextual chemistry, chemical peculiarities and methodological characters, living ESD and ESD competencies. The categories constitute different aspects of a complex and overlapping whole. Everything must be taken into account to obtain a holistic perspective on ESD.

Competence in the Jegstad model [12] which is considered important to back sustainable development actions, namely: problem solving, systems thinking, critical thinking, creativity action competencies, future thoughts and beliefs, normative competence, collaboration and communication. Developing competencies is seen as a continuous lifelong learning process. The importance of different competencies varies across regions of the world according to cultural norms, access to technology and social relations and power [26].

The main aspect of the competency concept is the ability to transfer competencies from a situation and use them in other situations. The aim is to identify broad enough competencies to cover various ESD nuances and aspects while sufficiently focusing on one or more of the aspects to be evaluated [8], [12]. Similar to the Holbrook education concept [23] through chemistry, chemical education can be a place for students to improve their ESD competencies and to gain chemical knowledge, which can lead to independent learning.

Other researchers develop ESD training through the following main parts: 1) chemistry and teaching in contexts (e.g. climate change), 2) four dimensions of sustainable development, 3) Pedagogical Content Knowledge (PCK) and 4) utilizing modern technology in teaching sustainable chemistry and the possibility of collaboration occurs with industry, companies and research units [9]. Briefly the concept of sustainable development in chemistry education from the source of the articles reviewed is presented in Table 1.

Table 1. Results of ESD in chemistry education article review

| No | Author | Results |
|----|--------|---------|
| 1  | Zoller, U. (2012). *Journal of Chemical Education*, 89(3), 297–300 | Important recommendations for adopting a sustainable environment: 1) Environmental chemical literacy for global sustainability must be a must for all; 2) To achieve this literacy requires an interdisciplinary conceptual approach in teaching and evaluating Higher Order Cognitive Skills; 3) Chemical and science education for sustainability is a must in science education; and 4) Science education (and especially chemistry education) addresses issues that are relevant to global sustainability. |
| 2  | Jegstad, K. M., & Sinnes, A. T. (2015). *International Journal of Science Education*, 37(4), 655–683 | Jegstad’s ESD model provides a perspective for developing sustainable chemistry education in the current chemical curriculum. Overloaded subjects are one of the challenges shown by the teacher when trying to realize ESD in the classroom. Therefore the Jegstad’s model presents ways to realize ESD in chemical education without adding more knowledge content to the curriculum. The ESD elliptical model in chemical education was |
developed to support teachers in realizing their ESD and therefore can be presented during in-service and pre-service teacher education programs.

3.2 Concept system thinking for sustainable chemistry education curriculum

Various perspectives, understandings and opinions about systems thinking have been widely reported by researchers. Arnold and Wade define System Thinking as a set of synergistic analytical skills to enhance the ability to identify and understand systems, predict their behavior, and design their modifications to create the effects desired. These skills work together as a system [19, 27]. Meanwhile, Sarah York defines system thinking as a holistic approach to investigating real-world systems that are complex, not focusing on the individual system components but on the dynamic reciprocal relationships between components and on the behaviors and patterns that arise from these reciprocal relationships. The history of the emergence and development of thinking systems in chemistry education the authors recommend to examine further in the MaryKay Orgil article [21].

Each of the systems has three main characteristics at least: 1) parts / components; 2) component interconnections, and 3) objectives [21]. Operationally Systems thinking is defined as the ability to comprehend and interpret complex systems which involves the following: 1) visualizing relationships and interconnections between system parts; 2) checking behavior changes over time; and 3) examining the rise of system level phenomena from interactions between system parts [21].

We can achieve the systems thinking perspective on chemical education by investigating environmental and socio-economic factors. Furthermore, thinking system is also related to local and international issues, so it requires interdisciplinary thinking in a holistic manner and understanding causality as an important prerequisite for getting involved in sustainability issues and as part of system thinking [12, 14]. Therefore system thinking according to experts can be defined as an approach or skill needed for a sustainable chemical education curriculum [21].

System thinking as an approach is to research and learn concepts from a holistic perspective. The roots of the modern system thinking approaches are in the mid-20th century. There are many significant developments informed by the biology field even though system thinking has been influenced by philosophies, concepts, and methods from various fields, including philosophy, sociology, organizational theory, and thought feedback. Ludwig von Bertalanffy is, in general, regarded as the father of the system approach [28].

System thinking as a skill can be explained further through examining the unique skills and competencies shown by system thinkers. There is no consensus of systems thinking skills that should be developed by students even though there are several lists of systems thinking skills in the literature. Until now, there is no specific chemistry list for systems thinking skills. The thinking skills of the system chosen in this article are based on Systems Thinking Hierarchical Models and Seven Systems Thinking Skills of Richmond [21]. The comparison of skills is shown in table 2.

Table 2. Comparison of system thinking skills

| No | Systems Thinking Hierarchical Model | Richmond’s Systems Thinking Skills |
|----|------------------------------------|-----------------------------------|
| 1  | The ability to identify the components of a system and processes within the system | Dynamic thinking                   |
| 2  | The ability to identify relationships among the systems' components | System-as-cause thinking           |
| 3  | The ability to identify dynamics relationships within the system | Forest thinking                    |
| 4  | The ability to organize the systems' components and processes within a framework of relationships | Operational thinking               |
| 5  | The ability to understand the cyclic nature of system | Closed-loop thinking               |
6. The ability to make generalization

7. Understanding the hidden dimension of the system

8. Thinking temporally, retrospection and prediction

Research and learning of science including chemistry, as informed by the system thinking perspective, focuses on the things as follows; 1) a system as a whole and not just as a part; 2) changes in system behaviour over time; 3) variables causing system behaviour and not variables correlating with system behaviour; 4) organization and reciprocal relationships between parts of the system; 5) the organization and reciprocal relationships between parts of the system produce unique characteristics that emerge at the system level; 6) interaction between the system and its environment (including human components of the environment); and 7) democratic participation, collaboration, and ethical action [21].

System thinking allows individuals to see high-level behaviors and phenomena that might not be predicted to appear only from several system component parts. Systems exist at various scales, which include microscopic, macroscopic and mesoscopic, with boundary conditions for certain systems defined by the observer [21]. This concept is in line with the nature of chemistry which has the characteristics of representation. Chemical representation has also experienced various developments [29–31]. The newest concept of chemical representation is adding human elements to the chemical representation system. The development of chemical representations is briefly presented in Table 3.

Table 3. Development of chemical representations

| Author                          | Term used               |
|---------------------------------|-------------------------|
| Johnstone, 2000                 | Macro                   |
|                                 | Sub-micro               |
|                                 | Representational        |
| Treagust, Chittleborough, & Mamiala, 2003 | Macroscopic            |
|                                 | Sub-microscopic         |
|                                 | Symbolic                |
| Mahaffy, P. G., 2005            | Human element           |
|                                 | Macroscopic             |
|                                 | Molecular               |
|                                 | Symbolic                |

The results of further studies on systems thinking in chemical education have been reported by researchers. Like research on connecting systems of thinking and learning services in chemistry classes [18], how to assess chemical systems thinking skills [19], implementation of system thinking in STEM education [20] and system thinking as a lever of changes in chemical curriculum [22].

4. Conclusion

Chemical education has the main role in education for sustainable development. This concept of sustainability is in line with system thinking. System thinking is a holistic approach to investigating complex real-world systems, not focusing on the individual components of the system but on the dynamic reciprocal relationships between components and on the behaviors and patterns arising from the reciprocal relationships. System thinking can be defined as an approach or skill. System thinking as an approach is to research and learn concepts from a holistic perspective. Systems thinking as a skill can be explained further through examining the unique skills and competencies shown by system thinkers. System thinking that leads to holistic thinking to solve local or global problems makes thinking this system can be used as an approach or a skill that can be taught and trained in a chemical education curriculum.
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