Exploring the Possibility of Embedded Sustainability and Humanitarian Principles into Chemical Studies from a Systems Thinking Approach

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Abstract

The laudable intent of science and industrialization for the ease, long life and comfort of humans has resulted in degradation of the ecosystem as pollutants from chemical production and their use end up in the ecosystem and exert detrimental effects on systems. This damaging effect has translated into climate change, food crisis, financial crisis, poverty, water scarcity, poor health, war, injustice, migration and urbanization, and other humanitarian challenges. A sustainable and humanitarian solution must be found to mitigate the existing and subsequent challenges. A possible solution could be through the development of sustainability- and humanitarian-literate citizens through chemical education. To explore this possibility, 31 preservice graduate teachers were engaged in a case study where they developed solutions to real life environmental challenges in a safe, fun-filled environment, with simple, cost-effective equipment from a system thinking stance. Data was gathered through questionnaire, inter-rated observation schedule, semi-structured interviews and lab reports. Findings indicated that it was feasible to embed sustainability and humanitarian principles through a system thinking approach to inculcate into preservice teachers the need to protect our ecosystem for posterity through chemical studies.

Keywords: Humanitarian, embed, ecosystem, microchemistry, sustainability, systems thinking

1. Introduction

Chemistry education and its practise has improved life on earth profoundly. Yet, some offshoots from the success of chemistry and other sciences have affected the ecosystem negatively [1]. This industrialisation has resulted in depletion of forests, soils, water, air, and some organisms faster than they can regenerate themselves. We tend to cut down too many trees, mine more than the world requires at any time and feed on or destroy other organisms faster than they can replace themselves [2]. These reigning factors lead to poverty, diseases, poor shelter, negative impacts on climate, less food, and unequal sharing of dwindling resources. It is evident that the world is heading towards a catastrophe and so it is binding on nations and teachers in particular to begin an educational transformation towards sustainability and humanitarian behaviours to avoid the looming world humanitarian challenges.

In order to develop sustainability-literate societies to save ecosystems, chemical education must be geared towards improvement and sustainability of the ecosystem so as to mitigate emerging humanitarian challenges, which have been observed to affect the marginalized in society who benefit less from the practice of chemistry [3, 4] and its many comforts. Teachers who have communities' mandates to teach for change in educational institutions must deliberately be re-educated and also go on to educate for sustainable development to enhance humanitarian living.

Sustainability is a construct that often refers to a concern for intergenerational equity [5]. It must be noted that the terms 'sustainability' and 'sustainable development' represent different ideas, though some authors use them interchangeably. Sustainability deals more with the interconnectedness among three pillars- environment, economy and society, while sustainable development implies 'continual growth' [5] and demands on resources, a discussion that would be beyond the context of this study. Ecologists define sustainability as the capacity of an ecosystem to sustain interdependent forms of life by balancing the rate of resource removal with the rate of resource generation [3]. Sustainability education extends, but does not replace environmental education or education for sustainable development (ESD) [6]. Educating citizens by introducing programmes that target teacher trainees who will teach future generations of learners the issue of sustainability, which principles they as teachers have acquired, is a laudable approach to developing a pro-environmental orientation. Changing orientations toward the environment, therefore, demands targeting the youth (and teachers) as they would mediate the environmental, humanitarian, and sustainability discourses of subsequent generations [8].

Humanitarianism, is an active belief in the value of human life, whereby humans practice benevolent treatment and provide assistance to other humans to reduce suffering and improve the conditions of humanity for moral, altruistic, and logical reasons. Another meaning for 'humanitarian' pertains to the practice of saving lives and alleviating suffering [1].

Developing humanitarian-literate and sustainable-literate citizens through a systems thinking approach, require the production of learners and graduates who are ready to display humanitarian and sustainable behaviours whenever and wherever the need arises. The role of teachers in this regard is important as they are expected to teach in a holistic manner to guide their students to develop concepts and skills that bear on sustainability and humanitarianism for transferable skills, lifelong living, care for the planet earth and world peace [3].

Many teacher training institutions, do not consciously pay attention to training teachers to acquire the necessary skills to inculcate sustainability and humanitarian principles in their future learners [7]. This is because most higher education curricula are still dominated by the mechanistic paradigm and would require a shift towards multidisciplinary, contextual, ecological and humanitarian paradigms [10, 11]

A solution to this dilemma could be to create awareness of the environmental impacts of chemicals, integrate project-based [8] and problem-based activities [9] into laboratory work, engage more in regenerative, green and microchemistry, and above all, educate for sustainability [10, 11] with the aim to apply knowledge gained to solve humanitarian challenges within living spaces from a systems thinking approach. The possible resolution of such a dilemma would be the focus of this study.

Systems thinking approaches emphasise the interdependence of components of dynamic systems and their interactions with other systems, including societal and environmental systems. Such approaches involve analysing emergent behaviour, or how a system as a whole behaves in ways that go beyond what can be learned from studying the isolated components of that system; the characteristic or traditional way of studying chemistry and other disciplines.

Reorienting chemical education for sustainability and humanitarianism through systems thinking can foster the growth of systems thinking skills in addition to teaching the principles and practice of chemistry. Systems thinking skills have been recognised as a key competence for education for sustainable development [14], and practitioners of education and educators have a duty to help students develop their system thinking skills so as to be able to meet global challenges in the present and future (Mahaffy et al, 2019). UNESCO's key competencies for sustainability are: 1) systems thinking competency, 2) anticipatory competency, 3) normative competency, 4) strategic competency, 5) collaboration competency, 6) critical thinking competency, 7) self-awareness competency, and 8) integrated problem-solving competency [12, 13].

UNESCO's key competencies for humanitarianism are about the same as for sustainability. It looks basically at people affected by disaster and conflict and strengthen behaviours that are critical to rendering assistance. Humanitarian principles are a set of principles that govern the way humanitarian response is carried out. UNESCO's adopted principles are humanity, neutrality, impartiality and independence [1].

This paper looks at the possibility of embedding these sustainability and humanitarian principles into chemical education from a systems thinking approach, with the hope that its integration and outcomes would equip societies with the necessary knowledge and skills to adopt best practical practices that would enable them to cope with environmental exploitation and associated humanitarian challenges. These challenges necessitate a search for new paradigms in teacher education, such as systems thinking, to bring about a positive change through sustainability and the empowerment of citizens [14].

Sustainable development is an important topic. It is a pattern of resource use that aims to meet human needs while preserving the natural environment so that these needs can be met not only in the present, but in the indefinite future.

In this document, I will provide an outcome of a baseline study where the use of microchemistry was embedded as a laboratory-based pedagogy in teaching chemistry. Adaptations that were made to the regular chemistry curriculum to produce an integrated microchemistry curriculum would be narrated briefly, as it is not the object of this current exposition.

Chemical education dwells on pedagogical practices [15] to teach the rudiments of chemistry practical activities [9], the nature of chemicals, safe quantities to use, waste management and the impact of chemical activities on the environment. Yet, students assume an uncooperative stand and do not engage with such an important course (discipline) as expected because they see the study of chemistry principles as monotonous, dangerous, and a disconnection between real life requirements for long-life living and chemical principles [1]. Some also have a fear for practicing in the lab because of dangers such as cuts from broken glassware, explosions from wrong chemical activities and the long hours that must be spent before results are achieved. Thus, the use of micro and nano equipment has recently been suggested to solve these existing problems with labs.

The microchemistry equipment which was employed in this current study was a box that contained miniature plasticware that required the use of minimal chemicals in the range of 0.1 to 0.5 mg of solid and 1 to 5 ml of solution. Microchemistry is a branch of chemistry responsible for making school science (chemistry) less dangerous to users and the environment. A picture of the microchemistry kit is shown as Figure 1.

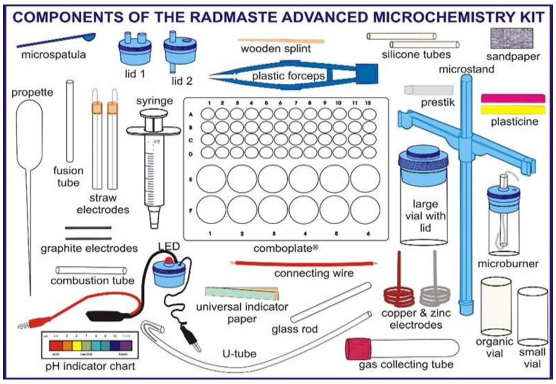

Figure 1. A schematic diagram of a microkit kit

No literature was found, at the time of this study, on how the integration of sustainability and humanitarian education into chemistry education from a viewpoint of systems thinking could explicitly advance the course of mitigating humanitarian challenges and saving ecosystems for now and he future. This served as a basis for this study because the importance of science, technology and innovation has been recognized with regard to the sustainable development goals and other frameworks such as the planetary boundaries as well as the need to tackle the depletion of the world's elemental resources and wellbeing.

2. Problem statement

Graduate chemistry students (preservice teachers) at a teacher education institution in Ghana conducted labs with drudgery and disposed of organic, inorganic and other chemical waste indiscriminatory. They showed disregard for sustainability principles [16], and its implications on the environment and subsequent humanitarian challenges. They also had little knowledge about teaching chemistry 'without borders'; that is, from the complex systems idea. An overarching question that guided this study was:

- What constructivist lab practices could enhance efficient chemical use and chemistry concept formation that would link the application of chemical knowledge to sustainability and humanitarian issues from a 'systems thinking' viewpoint?

3. Methodology

The case study with interpretive undertones was set in a positivist paradigm, while the constructivist theory underpinned the study. Problem-based, inquiry-based activities that required the integration of systems thinking approaches were adopted in the assignment of practical activities. These approaches were employed because they enabled pedagogies that could be used to contextualise chemistry education and involve students in real-life environmental problem-solving tasks [17]. An intact class of 31 graduate students who enrolled in the researcher's class were purposively selected to participate in the study. The research instruments were a five-closed and two-open item questionnaire, a semi-structured focus-group interview schedule, an inter-rater observation schedule, and project reports. Ethical considerations and trustworthiness of both method and data were ensured. The SPSS and N-VIVO (coding and thematic approach) were employed for data analysis of quantitative and qualitative data respectively. Specifically, descriptive statistics software from the SPSS package was employed to assess students' entry and exit cognitive growth, though not reported in this paper. A qualitative aspect of the study was reported in this article.

The embedded chemistry topics were on environmental resources, atmospheric, aquatic and soil chemistries, pollution and its effect on the ecosystem, economic impact of cleaning waste/environmental damage, health and diseases, and designed microchemistry labs that connected school chemistry to practical life chemistry as well as basic toxicology. The lessons were developed based on the ADDIE (analyse, design, develop, implement, and evaluate) model [18] and the integration change model [23, 24] as shown in Figures 2 and 3. The ADDIE model is shown below as Figure 2.

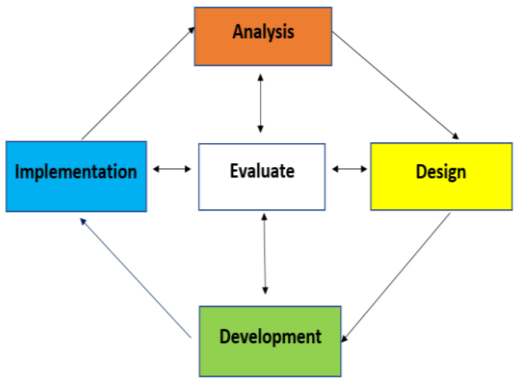

Figure 2. The ADDIE Model

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The ADDIE model allows for change through a system- based approach. The integration change model shown in Figure 3 was also adapted for the inclusion of connection with major sustainability and humanitarian integration stakeholders.

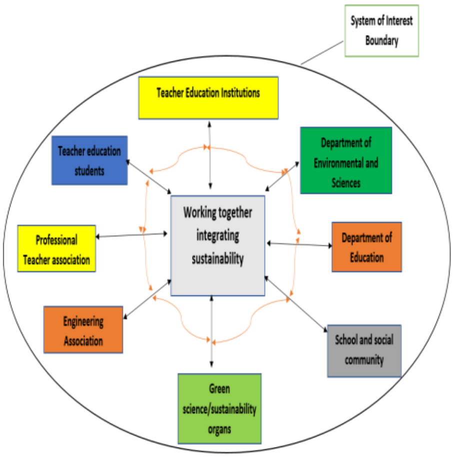

Figure 3. The Adapted Integration Change Model

Table 1. A model lesson outline of embedded sustainability and humanitarian ideas in marine chemistry

Topic	Sustainability and humanitarian topic	Strategy for implementation
1.Occurrence of water	Availability and cost of water (production)	Let us think of sources and abundance of water. How easily and cost-effectively could water in diverse regions like the desert and wet areas of the world be harnessed? Discuss some effects of water scarcity on life
2. Molecular structure of water	Chemical bonding in elements of water (Importance of hydrogen bonding) Water's universality Production cost	1.We will look at the feasibility and cost of manufacturing water on small and large scales as well as the universality of water in industrial chemistry 2.Outline best packaging and transportation processes to a water-scare region in Africa with reasons.
3. Nature of ocean water	Differences between fresh and sea water Harvesting of water Preservation of fresh water Production of fresh water from sea water (desalination: Reverse and nano osmosis)	1.In groups, discuss the differences between various sources of water, their harvest, and preservation Project: 2.Obtain a measured volume of sea/polluted water and design a process for maximum yield of fresh water
4.Natural chemicals in the sea	Benefits and otherwise of chemicals found in the ocean Chemical interactions of chemicals Effect of chemicals and their interactions on aquatic life and beyond How natural chemicals affect ocean circulation, ecosystems and affect human activities	1.Students work in groups to practice multi-criteria sustainable decision making 2.Debate session on nutrients and ocean acidification 3.Work out the speciation of N and P in water through mapping 4. Whole class discussion on pollution
5. Veterinary residues	Contaminants in seafood bioaccumulation	1.Discuss risks associated with water and food contamination 2.Enact how policies and human rights become fundamental in creating sustainable communities 3.Develop a workable water-use policy

This model also makes provision for educators to become reformers and activist, leading to sustainability and humanitarian literacy through a holistic, systems thinking concept approach. An example of an embedded lesson on marine (aquatic) chemistry that incorporates ideas to inculcate the idea of sustainability and humanitarianism from a systems approach is shown as Table 1.

From Table 1, we can see how hither-to basic chemistry topics that were compartmentalised have been embedded with contemporary context-based sustainable and humanitarian developmental issues through holistic systems thinking approaches.

Challenges (tasks/projects) were assigned to students a week before their field or lab work for adequate research and collaborative pre-lab discussions. A 30-minute prelab was observed before each project. An example of a project or 'challenge' is shown as Appendix A. sample items from the questionnaire that assessed participants' views after their course work is shown as Appendix B.

4. Analysis of findings

The administered questionnaire was based on UNESCO's 2017 key competencies for sustainability [13] and students' personal impressions about the embedded lessons for sustenance. Findings from the questionnaire were that activities mirrored real life occurrences and so students were motivated and engaged through the chemistry practical sessions. The students indicated that transferrable, concept and lifelong skills were acquired. They also gained understanding about the principles of sustainability and humanitarianism through the micro activities. Waste management to mitigate pollution was a key awareness factor that gained high consideration. The students intimated that the new approach led them to see how most disciplines were interconnected and needed to be appreciated and applied as such in understanding and solving everyday life challenges connected with justice and equity, climate, health, food supply and poverty. This observation was made in similar studies by Mahaffy et al. [19, 10] and Grosse [21].

4.1. Findings from observation schedule

An observation schedule that had an inter-rater value of 0.84 was used while students carried out group and independent projects that were to equip them with the necessary sustainability and humanitarian principles and skills, Findings from the observation sessions showed independence in solving problems, though there was increased fun, communication and collaboration as well as tolerance, among students. Students engaged better with the embedded course and demonstrated a desire to mitigate challenges that existed within the school and their local communities through acquired knowledge and sustainability practices than was informally observed in previous years.

4.2. Findings from focus group interview

Findings from the focus group interview sessions with five students (more than 10% of the sample) corroborated what was gathered from the observation sessions. Students added that the multidisciplinary nature of the chemistry lessons and the use of the microchemistry equipment allayed their initial fear, drudgery, and diffidence associated with conventional labs where large-sized standard glassware equipment that required the use of large volumes of chemicals were employed. Mc Donnel, O'Connor and Seery [9] made similar observations of fear for practical work and lack of motivation when students had to use standard or conventional glassware for lab activities, but were motivated and participated fully in labs with understanding when micro equipment and basic home chemicals were employed for lab and home practice of chemical studies. The students in the current study were happy that they no longer had to generate copious chemical wastes, to the detriment of their health and the environment as a whole. They were convinced without doubt that the minimised waste would reduce environmental degradation and result in better health, cleaner environments, water, soil, climate and food as found in a similar study by Hanson and Hanson [3] and Mc Donnel et al. [9]. These findings are supported by students' quotes which were obtained at a point of data saturation.

- *The projects are encouraging as they motivate me to work more because time required for activities are shorter and labs are safer.*
- *Activities mimicked real life occurrences caused by human activities, so we had to develop real workable solutions to solve them.*
- *The microchemistry labs highlight innovations that can move society towards using less resources in sustainable ways for posterity.*
- *Activities demand careful planning and strategizing so one must be wise and think critically.*
- *We often had different challenges and so could not copy each other's work. That was good for our own cognitive growth and independence.*
- *Pollution was minimised in the lab and the community unlike when we produced so much waste with the big glasses that we also disposed of anyhow.*

4.3. Findings from laboratory reports

The lab reports showed evidence of conceptual gain (not shown in this article) by well-structured and communicated lab reports which scored higher marks than before this study. Students demonstrated their understanding of sustainability and humanitarian challenges through their context-based hands-on activities lab reports and provided solutions or mitigating alternatives for identified challenges.

4.4. Interpretive findings

Interpretive analysis of gathered findings from administered questionnaires, observation schedule, conversation and laboratory reports revealed many findings, some which confirm that identified by other researchers. A few are listed below:

- Chemistry practical activities/labs could be extended outside the walls of school labs.
- Microchemistry has the potential for enhancing the principles of humanitarianism and sustainability as identified by Hanson and Hanson [3].
- Humanitarian challenges could be solved through chemical education as also found by Mahaffy et al. [15].
- Constructive teaching approaches that are context-situated could be encouraged through the use of microchemistry kits as opined by Bell [8] and Arroio [17].
- Hands-on and real-life projects with microchemistry kits makes the learning of chemistry and principles of humanitarianism and sustainability joyful as it removes the fear and drudgery of conventional labs and practices [9].
- Increased self-directed learning.
- Need to enforce waste disposal management plans in school labs and communities [16].
- Awareness of implications of chemical waste heightened.
- Step up exposure to real-life challenges for the practice of humanitarian and sustainability principles as proposed by Hanson and Hanson [1] in other studies.
- Increase in systems thinking competence.

5. Recommendations

Based on gathered data and conclusions that were drawn from the findings, the following recommendations are made:

- There is a possibility of embedding principles of sustainability, humanity, neutrality, impartiality and independence into chemistry courses in the Ghanaian university that participated in the study
- A multidisciplinary approach to teaching is recommended
- Chemistry labs/projects/challenges must be conducted with fun and contextualized for students to appreciate the relation between chemistry, theories and day life
- Chemistry teachers must create awareness of effects of environmental pollution among their students
- Sustainable approaches to performing chemistry labs such as the use of micro science equipment and green chemistry should be more than regular/conventional labs so as to minimize the generation of chemical and other wastes.

6. Conclusion

The use of project- and inquiry-based micro activities with embedded sustainability and humanitarian principles in regular labs through a system thinking approach could build connection between chemistry theories/labs and real-world challenges as students demonstrated adequate understanding of desired principles through practical applications. They performed their assigned labs/projects with joy, collaborated, communicated findings coherently, and learned to manage waste better, as they understood its immediate and long-term implications on humans, other organisms and the physical environment. The students also demonstrated the acquisition of cognitive, sustainability, and humanitarian concepts and skills that are required to manage themselves, other people, their communities and the wider world to make it a better place to live in now and for future generation. It could therefore be concluded that the adopted constructivist lab practices and systems thinking strategies had the potential to enhance concept formation that could link the application of chemical knowledge to humanitarian and sustainability issues.

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Appendix A

Lab Challenge (Project)

A farm manager has succeeded in getting rid of pests on his vegetable patch and produced bigger, plentiful yields of healthy-looking okra by applying a propoxur-based pesticide, besides fertilisers monthly. Other community farmers close to the river along the farm that supplies the community with water have lodged complaints that activities on the said farm have contaminated their source of water and must be sued.

Follow up questions for identified challenge

Find out if there is any truth in the assertion/complaint made by the inhabitants.

Produce evidence to support your answer. (Use micro kit if lab works must be performed).

Consider the immediate and long-term effects of your response on both the university and the community as well as remediation activities/processes if necessary.

Consider the structure of propoxur and propose other ways by which a safer and eco-friendly chemical could be produced for use on farms.

Show a scheme for the preparation of the new 'green' product that can replace propoxur.

Appendix B

Sample close and open items from the questionnaire

(Guiding instruction and options not shown)

Sample of **close** item		
No.	Item	What to assess
1.	I am able to detect environmental and humanitarian challenges and prescribe possible solutions	Anticipatory, normative, strategic and critical thinking competencies
2.	I prefer to work with minimal volumes and quantities of chemicals than with standard resources	Self-awareness, strategic and normative competencies
Sample of **open** item		
1.How will you disseminate policy on environmental preservation to your colleagues and community members? Why would it be necessary to do disseminate such information? *This will involve analysis of the policy and the adoption of a systems thinking competency approach*.		
2.The situation in Ketekrom concerning famine, lack of water and outbreaks of diseases has become an international concern. As a student of this course embedded with sustainability and humanitarian principles, how could such a problem have arisen and how do you anticipate its solution? *This problem could be tackled from an integrated problem-solving competency, critical thinking and humanitarian principles.*		

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