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Science Teachers' Perceptions of the Systems Thinking Approach for Teaching and Learning Sustainability at Secondary Schools

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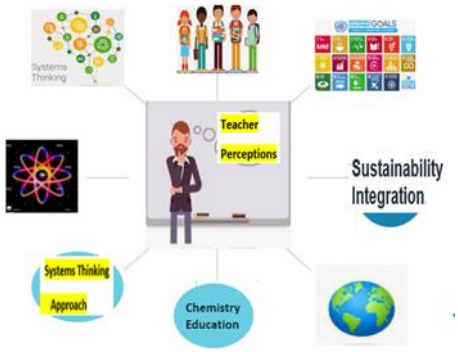
ABSTRACT

This paper presents the views of chemistry teachers about systems thinking through the concept of sustainability. The need for this study arose from the fragile nature of the climate, ecosystems and societies and how teachers as the drivers of new ideas for social, cultural, economic and financial development must play a role to maintain the earth's system through a more holistic approach to teaching. It has become important to identify topics in the syllabus that lend themselves to the practice of sustainability through systems thinking for the proper use and conservation of the earths' dwindling resources, mitigate overuse of carbon and its attendant effects, deal with climate change and reduce humanitarian challenges. Views of 40 in-service teachers were sought through a google survey to find out how teaching and learning of sustainability concepts could be reimagined to meet the needs of the earth system through systems thinking, and reinforce the teaching about complex systems across disciplines. Findings indicated that about 69% of in-service teachers perceived they had adequate knowledge about sustainability, but 75% had little to no knowledge about systems thinking. They admitted that there was the need for professional development courses in sustainability issues, and how they could be integrated into lessons using a systems thinking approach.



KEYWORDS: Chemistry teachers' Perceptions, Holistic approach, Professional development, Sustainability, Systems thinking.

1. INTRODUCTION

From research studies, sustainability principles and systems thinking are important to contemporary education and training.[1,2] Future teachers who apply systems thinking and sustainability approaches to life may enhance their potential to understand and solve some of the current and emerging global challenges as outlined by the United Nations Sustainable Goals and teach the same to their prospective learners.[3] Sustainability and systems thinking theoretical frameworks could be used as instructional models to facilitate desired change in science education.[2]

1.1. Sustainability

Sustainable development (SD) is development that meets the needs of the present without compromising the ability and needs of future generations.[4] Increased awareness of the importance of sustainable development, and the essential role that education could play, led to the development of the concept of Education for Sustainable Development (ESD). ESD is understood as an education that 'allows every human being to acquire the knowledge, skills, attitudes and values necessary to shape a sustainable future.' This means 'including key sustainable development issues into teaching and learning; for example, climate change, disaster risk reduction, biodiversity, poverty reduction, and sustainable consumption. Furthermore, the knowledge of content and suitable teaching strategies is required to infuse environmental sustainability (ES) into lessons so as to unleash the potentials of sustainability education.[3]

ESD is arguably at the heart of the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs).[5] The adoption of the 2030 Agenda for Sustainable Development has provided fresh impetus for Education for Sustainable Development. Under Goal 4, it is widely recognised that one of the most ambitious, interesting and challenging targets is Target 4.7,

which aims to: "By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through ESD and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and nonviolence, global citizenship and appreciation of cultural diversity and of culture's contribution to sustainable development". Achieving these goals requires a profound transformation in the way we think and act, [6] especially how classroom teaching and learning is enacted.

In order to implement ESD, it is important to review learning environments and encourage the whole-school approach. ESD calls for more focus on the integration of the pedagogies and thematic areas of ESD into training of teachers and trainers. It is interdisciplinary and transdisciplinary, meaning that no discipline can claim ESD as its own, but all disciplines can respond and contribute to ESD individually and/or collectively. New approaches that allow for holistic multidisciplinary teaching must be adopted, of which the systems thinking approach could be one.

1.2. Systems Thinking

Systems are combinations or groups of interrelated, interdependent or interacting components that form distinct collective entities. The outcome of the combinations, like a hybridised system functions better than if each were an individual component. A system could be non-material or physical. Systems thinking is therefore a set of synergistic analytic skills used to improve capability to identify and understand systems, predict their behaviours and devise modifications so as to produce desired effects. It is believed that these desired skills provide the ability to visualise, articulate, and solve uncomplicated and complex problems and concepts. This will enable the making of sensible decisions based on concrete available information.[7]

Systems thinking does not have a specific definition as slight modifications are possible depending on their different applications.[2,8] However, it can be viewed as a 'holistic approach for examining complex' real-world systems, in which the focus is not on the individual components of the system but on the dynamic interrelationships between the components and on the patterns and behaviours that emerge. Systems thinking has been applied in biology, economics, management, engineering, and the business world.[8,9]

Chemists can look at matter within the environment and not lose sight of its' particulate nature.[9] The authors reiterate that systems thinking approaches should emphasise the interdependence of components of dynamic systems and their relationships with other systems, including cultural and environmental systems. Systems thinking has characteristics of problem-based and context-based learning. Using systems thinking concepts and tools together with context-based and problem-based learning approaches offers many opportunities to teachers. Furthermore, systems thinking approach would encourage problem-solving and knowledge integration that could span across disciplines.[7]

1.3. What is the possible role of science (chemistry) in the attainment of sustainability through systems thinking, within the sustainability development goals (SDGs) and ESD?

Chemistry is a central science that underpins basic aspects of a number of established and emerging sciences.[10] It must be acknowledged that chemistry has played a dual role in global development.[10] On a positive side, chemistry has provided knowledge and products such as energy, materials like polymers, plastics, semiconductors, pharmaceuticals, new vaccines as observed during the recent covid-19 pandemic, agrochemicals for crop protection and higher yields, and many more, so that it justifies chemistry's claim to be the 'quality of life' science par excellence. On a negative side, the processes and products of chemistry, have paradoxically, contributed to a myriad of emerging global humanitarian problems, especially in less developed countries that do not have the needed resources to combat the emerging negative effects. The most obvious of these negative effects are the resultant global warming, rising sea levels, depletion of the ozone layer and increasing litter from non-decomposing plastics. In order to avoid multiple crisis, the world's populace could be adequately educated on sustainability principles, and their benefits for now and posterity through a systems thinking approach.

Beyond the systems thinking approach, a conscious effort must be made to consider the integration of sustainability into school curricula, and also from the social sciences approach.[11] There

is, however, little evidence of awareness of the SDGs and their importance among most practicing chemists, especially teachers, as a baseline study showed.[1] There is also little knowledge about education for sustainability development, as a study on Estwani teachers research shows.[12] The researchers found that creating awareness of environmental sustainability among learners could be an effective way of helping citizens to deal with sustainability challenges and so teachers had to be trained on how to teach with sustainability concerns in mind.

In chemistry lessons, it is difficult to visualise or imagine studies of ions, atoms and molecules without a study of compounds and the interactions of the named particles. Yet, chemistry plays a role in linking chemical, physical, biological, ecological and human systems towards sustainability. Current sustainability challenges would require the knowledge from chemical scientists and other collaborators from other disciplines. In order to enact this idea, chemists would necessarily have to be educated to engage in systems thinking and cross-disciplinary approaches.

Chemical activities could be seen as processes that could be in parts, whole or interactive. As put forth, chemistry components interact with many other systems in the environment which could have positive or otherwise effects.[9] Studying chemistry as a dynamic system would help to focus on the interconnected components that are coherently organised to advance knowledge, deliver useful applications and solve challenges, while reducing risks and improving safety and sustainability as intimated earlier. The many parts of chemistry also interact with many other systems, such as the environment and affect biological, ecological, societal, economic and other systems. This means that curriculum changes would have to be made in existing curricula to cater for the new realisations on how education for sustainable development in all sectors of formal learning, could impact the earth's systems positively.

Ordinarily, the teaching and learning of chemistry must be able to equip citizens with requisite knowledge to cope in a changing world, but is that the case? Does our knowledge of chemical principles make the world better or worse? Thus, how systems of knowledge in various disciplines relate to one another, to societal or cultural systems, and the entire world, becomes a very important issue to consider. A reductionist approach in science education and research is not sufficient to address global challenges such as sustainability, pollution, climate change, and poverty.[13] A more holistic approach (systems thinking) must be adopted so that boundaries around systems can be removed for the interconnectedness of systems to be apparent. Research that supports holistic, interdisciplinary, and transdisciplinary action must be considered.[11,1,14,10] In-service teachers (herein also referred to as teachers) must therefore be knowledgeable about these new ideas of teaching and implement them in their future teaching lessons.

In Ghana, some authors explored the possibility of embedding sustainability and humanitarian principles into chemical studies from a systems thinking approach.[15] Participants in that study acknowledged that the negative effect of chemistry and industrialization had translated into climate change, food crisis, financial crisis, poverty, water scarcity, poor health, war, injustice, migration and urbanization, and other humanitarian challenges and there was a need to work toward mitigating the identified challenges, because they were able to connect the systems as if there were no boundaries. The researchers gathered that a possible solution could be through the development of sustainability- and humanitarian-literate citizens through chemical education. Findings from questionnaires, interviews and inter-rated observation schedules indicated that it was feasible to embed sustainability and humanitarian principles from a systems thinking approach to inculcate into teachers the need to protect our ecosystem for posterity through chemical studies.

There was yet another study that also engaged teachers in introducing the concept of sustainability and systems thinking into lessons, but from an 'indigenous knowledge' approach. Indigenous science is fast becoming a pathway to teach the principles of sustainability and green science towards sustainable development, management and conservation of the world's ecosystems.[16,17] This study sought to explore participants' own ideas about sustainability and 'green' practices through the indigenous multi-stage production of palm-oil.

The production of palm oil was chosen as the object of study and trajectory for propagating issues of sustainability in science education, because in Ghana, palm trees from which palm oil is produced, abounds everywhere, apart from the Northern regions. It was therefore a common and familiar point to

use in the indigenous science class to teach the principles of sustainability, its significance and green practices for preservation of natural resources from a systems thinking approach.

It is interesting to note that the Ghanaian science and chemistry syllabus for secondary schools do not categorically mention sustainable development, nor make references to systems thinking as one of its teaching approaches.[18,19] Neither do tertiary curricula mention systems thinking nor request that teacher trainers educate prospective teachers on education for sustainability development through it.[20] There are topics where sustainability issues through systems thinking could be incorporated. It is the singular role of the teacher to go through the subject content and identify topics with opportunities to adopt systems thinking approach to teach sustainability-inherent topics. Some common topics in official curricula for secondary and tertiary education in chemistry are:

S/N	Topic	S/N	Topic
1.	Particulate nature of matter	6.	Acids, bases and salts
2.	Elements, mixtures and compounds	7.	Metals
3.	Periodic property	8.	Organic chemistry
4.	Stoichiometry	9.	Chemical bonding
5.	Chemical reactions	10.	Industry and technology

A close study of the mentioned topics indicates that some of them easily lend themselves to and for the integration of sustainability principles and systems thinking in practical and contextual ways. Education for sustainability (ESD) through systems thinking does not require a new topic to be added to the curriculum but allows for an existing curriculum to be adapted to suit the needs of both the people and the environment.[14,15] Thus, a concerted effort must be made towards this revelation and institution

1.4. Gap

So far, the limited studies exploring teachers' knowledge of sustainability through systems thinking have focused mainly on university pre-service chemistry teachers and the design of integrated sustainability lessons using a systems thinking approach. A review of the literature revealed no studies or practices involving in-service teachers with more than a year of teaching experience. In this study, the term "practicing teachers" or "teachers" specifically refers to in-service teachers. This gap highlighted the need for the researchers to investigate the extent of in-service teachers' understanding of sustainability principles, systems thinking, and education for sustainability after sourcing for their perceptions.

2. RESEARCH QUESTIONS

1. What perceived knowledge do teachers have about sustainability?
2. What perceived knowledge do teachers have about systems thinking and its approach to teaching science?
3. What topics in the syllabus lend themselves to the teaching of sustainability principles and sustainable development from a systems thinking approach from teachers' viewpoints?
4. What are teachers' perceptions towards the integration of sustainability and systems thinking approach into their science lessons?

3. METHODOLOGY

In order to be able to answer the outlined questions in this case study, a mixed method approach was adopted where a 5-point Likert scale questionnaire to assess teachers' knowledge on sustainable development (SD) and education for sustainable development (ESD) and semi-structured interviews were employed to gather data on perceived knowledge of sustainability concepts and the systems thinking approach. Parts of the questionnaire contained open-ended questions to elicit the teachers' views on the relevance of sustainability to their teaching, whether they thought it was important for students to learn about sustainability, how they translated the ideas into their teaching, and if they required support with its integration from a systems thinking point of view. The interview items were built around the questionnaire items for the purposes of corroboration and the acquisition of in-depth views about the research topic, from participants. Eight participants were selected and interviewed. In

qualitative research, smaller sample sizes can still provide rich, in-depth insights, with studies indicating that fewer than 20 interviews can often be enough to reach data saturation.[21] The decision to interview eight participants, representing 20% of the sample, is justifiable based on other factors. First, the study's specific goals and the homogeneity of the sample support the use of a smaller subset. Additionally, the quality of the interviews, along with the depth of the discussion, ensures that valuable insights can be obtained from a reduced number of participants.[22] Practical considerations, such as logistical constraints or time limitations, also contribute to the selection of a manageable sample size, making this approach both practical and effective.[23] In this case, interviewing 20% of the participants allows for a focused and meaningful exploration of the research question, while still being feasible within the study's constraints.

A case study allows for multiple forms of data collection to improve the findings' reliability and trustworthiness. For this study, the researchers chose to use questionnaires and interviews. Since the researchers engaged more than one teacher each from a different school, the type of case study used is an embedded, multiple-case study, which allows one to find a more in-depth understanding of a case and extend the generalisability of the findings. The use of mixed method was to help with the reliability and generalisability of the study's findings.

Obtained data were analysed quantitatively and qualitatively. Combining both the in-depth, contextual views of qualitative data with the broader generalisations of quantitative approaches, mixed methods research can be used to produce a rigorous and credible source of data.[24] It also helps to build comprehensive understanding and enriches the evidence through different explored avenues. Furthermore, it does not only track intervention, if one is put in place, but provides opportunities for participants in a study to have a strong voice and share their experiences. Obtaining the quantitative findings and exploring them in-depth through qualitative means, is worth investigating.

The sample for the study was drawn from a population of science teachers in the Effutu Municipal Constituency in Winneba, Central region of Ghana. The study focused on 40 in-service science teachers who had taught for up to a maximum of ten years. A questionnaire on the length of continuity in science teaching, particularly chemistry topics, was used to screen the teachers and came up with a sample of eight science teachers, each from a different locality.

The philosophical position underpinning this study was that of the interpretivist worldview. An interpretivist paradigm is associated with the idea that individuals seek an understanding of the world they live in, and researchers rely fully on the participants' perceptions of the situation being studied.[25] This philosophy, [26] is relevant to this study as teachers are social beings constantly interacting with students, fellow teachers, parents and community members.

Ethical considerations were carefully taken into account throughout the data collection process. Quantitative data gathered was subjected to descriptive statistical analysis to provide a clear overview of the responses. Qualitative data, obtained after data saturation, was organised into various themes and subjected to in-depth discussion. Issues of trustworthiness were ensured. In line with Creswell,[25] the strategies used to improve the trustworthiness of qualitative data were member checking, triangulation of data and external audits.[27] also recommended that experts in the field of research should review research instruments. In this study, the researchers asked subject experts and experienced educators to review and comment on the questionnaires and supporting interview schedules. The researchers created model answers to some of the questions in the questionnaire. Obtained data from the instruments used, were then analysed with respect to the requirements of the guiding research questions.

4. RESULTS

In order to ascertain whether teachers considered sustainability and the systems thinking approach relevant to the teaching of science (chemistry) in a holistic manner to maintain and save the earth, questions were directed and data collected to answer questions that would reveal the teachers' perceived knowledge of the subject under study. For example, the questionnaire contained some closed items that teachers needed to show knowledge of, such as shown in Table 1.

Table 1: Examples of closed items

Item	Very familiar	Familiar	Somehow familiar	Not familiar	Not familiar at all
The concept of sustainability					
Rate your knowledge of sustainability					
How familiar are you with systems thinking approach?					

The items in Table 1 of the questionnaire were close-ended. Examples of the open-ended items were:

1. How did you hear about 'sustainability'? Explain
2. What is your idea about 'systems thinking'? Explain
3. Make a list of topics in the syllabus that you think can contain elements of sustainability
4. Which topics have you used to address sustainability issues holistically?

These responses required the participants to express themselves freely, and some of the mentioned ideas appeared more than once in other items.

The first research question (RQ 1) sought to find out about teachers' perceived knowledge about sustainability education. Data obtained is shown in Table 2.

Table 2: Responses on teachers' perceived knowledge about sustainability education

Categories	Very familiar	Familiar	Somehow familiar	Not familiar	Not familiar at all
Collated Responses (%)	43	26	31	0	0

The responses obtained indicated that more than half of the in-service teachers (67%) purported to have some knowledge about education for sustainable education.

Research question 2 sought to find out the perceived knowledge that teachers have about systems thinking and its approach to teaching science. Participants familiarity with the systems thinking approach was also assessed and the responses are presented in Table 3. This data was used to answer research question (RQ) 2.

Table 3: Responses on participants' knowledge about systems thinking

Categories	Very familiar	Familiar	Not sure	Not familiar	Not familiar at all
Collated responses (%)	0	5	20	25	50

The in-service teachers had practically no knowledge about the systems thinking approach to teaching science.

Research question 3 (RQ3) sought to find out topics in the science syllabus that teachers perceived lent themselves for the teaching of sustainability through a systems thinking approach. The topics that came up were nine in all. These were green economy, science and technology, energy, reproductive systems, farming systems and energy, earth science, industry and climate, waste management, and science and industry. After this provision, teachers' views on how often they integrated sustainability principles from systems thinking approach were sought, as shown in Table 4, to answer RQ 4.

Table 4: The integration of sustainability principles into lessons

Categories	I often do	I sometimes do	Not sure	I hardly do	Never do
Collated responses (%)	37	63	0	0	0

About 37% of participants responded that they often did, while 63% said that they sometimes did.

Table 5 gives an overview of teachers' perceptions towards the importance of the integration of sustainability into science curricula.

Table 5: Responses on perceptions towards the importance of integration of sustainability

Categories	Very important	Important	Not sure	Somewhat Important	Not important
Collated responses (%)	62	20	0	17	0

Table 5 shows that majority of the in-service teachers (62%) perceived the importance of the integration of sustainability education into existing curricula.

Table 6, which also answers RQ 4, gives an overview of teachers' perceptions of integration of systems thinking into science curriculum.

Table 6: Responses on the importance of the application of the systems thinking approach

Categories	Very important	Important	Not sure	Somewhat important	Not important
Collated responses (%)	53	10	20	17	0

In their responses to the importance of the application of the systems thinking approach, about half of the in-service teachers responded in the affirmative. Interestingly, from Table 6, only 63% indicated that the application of systems thinking was very important and important to their teaching of science

A further probe into what they thought about integrating sustainability principles and development into science lessons through open-ended questions and a focus group interview indicated that the teachers were not as prepared for the integration, due to little knowledge on it. They were divided on the question on how integrated sustainability lessons and education would contribute to their learners' awareness of global environmental issues and responsible citizenship. All the teachers agreed that it was important for students to be taught about sustainability issues holistically. Of eight teachers that were sampled for the interview, one did not explain why she thought it was important. These were some reasons given by the seven other teachers on the integration of sustainability principles:

- "*Students are our future leaders and persons of influence in the country"*
- *"To help make use of our natural resources without depleting them".*
- *"We are currently faced with the problem of warm weathers, rising sea levels and global warming which have resulted in change in weather patterns and humanitarian challenges. If students and everyone is aware, it would mitigate the challenges"*
- *"So that they can be part of the practices and implementation of sustainable development policies and strategies"*
- *"They are the present generation who will carry forward the message of sustainability practices in a more practical and meaningful way to the next generation"*

All of these reasons given by the teachers emphasised their understanding of the important role that learners must play in caring for the environment, passing the message of sustainability on and conserving resources so that future generations can also benefit from them.

When the teachers were asked about problems that could be anticipated with the integration of sustainability principles through the systems thinking approach they opened up to some possible challenges. Some of the issues that they came up with as current and anticipated barriers were:

- Lack of curriculum support
- Time constraints as per the current timetable
- Lack of resources to facilitate work within the constrained time
- Lack of support from administrators
- Lack of professional development opportunities

On the question of provision of support, the teachers unanimously agreed that they would be interested in receiving professional development in how to integrate sustainability principles and sustainable education through a systems thinking approach. They went on to enumerate some of their expectations during such training. They admitted that, to engage in ESD they would require training in:

- how to redesign their lessons
- the application of the Analysis, Design, development, implementation and evaluation (ADDIE) model or principle in their integration
- increased content knowledge about sustainability principles and educating about sustainability
- increased content knowledge on education for sustainable development

- systems thinking
- green economy
- climate change issues
- recycling of waste to prevent pollution
- conducting science activities on a small scale

The teachers mentioned that they needed resources to add meaning to their teaching of integrated or sustainability-embedded lessons holistically. They vaguely said that 'common resources' for teaching would have to be provided by their supervising authorities.

5. DISCUSSION AND SUMMARY

The results regarding teachers' familiarity with sustainability in education from a systems thinking approach showed varying degrees of understanding of the concept. When combining responses in the 'very familiar' and 'familiar' categories, a total of 69% of teachers demonstrate some level of familiarity with sustainability as observed from findings for RQ 1. This is a positive indication, suggesting that a good number of the teaching staff possesses at least a foundational understanding of the concept. However, the breakdown into the 'somehow familiar' category (31%) raises some concern on the level of familiarity. It would be beneficial to investigate the specific aspects of sustainability education that teachers find somewhat familiar, as this information could guide targeted efforts in professional development. Notably, there were no responses in the 'not familiar' or 'not familiar at all' categories, indicating that, among the surveyed group, there is no lack of awareness or knowledge about sustainability in education. These findings imply a solid foundation to build upon. Curriculum developers and professional development programmes can capitalise on this existing familiarity to deepen teachers' understanding and seamlessly integrate sustainability principles more comprehensively into educational practices to be in line with the United Nations Sustainable Development Goals and the Brundtland Convention targets.

It is noteworthy that there were no responses in the 'not sure' category, suggesting a level of conviction or clarity among respondents regarding the importance of sustainability. The breakdown into 'somewhat important' (17%) reflects a need to investigate the reasons behind this moderate level of importance to provide valuable insights into the specific factors influencing their views.

The absence of responses in the 'not important' category implies that none of the teachers outrightly dismissed the idea of integrating sustainability from a systems thinking approach into the science curriculum. This absence could be seen as a positive indicator for advocates of sustainability education.

To gain understanding of the varying degrees of importance, especially in the 'somewhat important' category, further exploration through follow-up interviews or surveys could provide qualitative data to inform strategies for curriculum development and teacher training.

The strong support for the importance of sustainability in the science curriculum aligns with broader educational goals related to sustainability and environmental literacy. These findings can serve as a basis for advocating policy changes or enhancing the curriculum.

In contrast to the teachers' response on sustainability, the study revealed a significant gap in in-service teachers' familiarity with the systems thinking approach in teaching science, with only 5% claiming to be 'familiar.' This suggests a potential gap in teacher training. Hence, targeted initiatives are needed to equip teachers with the knowledge and skills associated with systems thinking, as indicated by the high percentages in the 'not sure,' 'not familiar,' and 'not familiar at all' categories. These current observations are similar to other observations that have been made in earlier studies.[8,6]

From the findings for RQ 2, the noteworthy 50% of participants responding 'not familiar at all' suggests possible misconceptions or a complete lack of awareness regarding the benefits of systems thinking in teaching science. Given the low familiarity, there is an opportunity for professional development programmes to bridge the knowledge gap in applying systems thinking in the science curriculum. This aligns with the importance of ensuring that teachers have the necessary tools to implement contemporary pedagogical approaches.[15,7,2]

In response to RQ 2, the study indicates minimal participant knowledge about the systems thinking approach. This prompts further exploration into how introducing systems thinking could impact science

education and teaching practices, opening avenues for pedagogical advancements as some researchers have also realized.[9]

The identification of nine diverse topics (from RQ 3) within the science curriculum that inherently contain sustainability-related issues, as purported by the teachers, such as green economy, energy, and waste management, emphasises the interdisciplinary nature of sustainability. This suggests that sustainability and systems thinking principles can be integrated across various science subjects. While 37% of participants claimed to often integrate sustainability principles into their lessons, the majority (63%) (See Table 4) said they did so only sometimes. This assertion also indicates a potential gap between teachers' self-perceptions and their actual integration practices, revealing a need for closer examination of their beliefs and necessary support for integration.

The participants provided insights into the perceived importance of integrating sustainability and the systems thinking approach into the science curriculum. The study's results (from RQ 4) regarding the perceived importance of integrating sustainability into the science curriculum among teachers show that a combined 82% of respondents, consisting of 62% selecting 'very important' and 20% choosing 'important,' express a positive view on the relevance of this integration. This indicates a clear recognition among teachers about the significance of incorporating sustainability principles into science education.

A substantial 53% of teachers regarded the integration of systems thinking as 'very important,' demonstrating a strong acknowledgment of its significance in science education. An additional 10% of respondents, recognising it as 'important,' further affirmed the positive view on incorporating systems thinking into the science curriculum. This support aligns with broader educational goals that emphasise critical thinking, interdisciplinary understanding, and holistic problem-solving. The findings suggest and confirm that systems thinking could be a valuable tool in achieving these educational objectives by in-service teachers on the field.[1,7] However, a portion of participants (20%) expressed uncertainty, and another group (17%) considered it 'somewhat important.' These responses among a minority of participants highlight the need to explore specific factors influencing their views. Further investigation through follow-up interviews or surveys could provide qualitative data to inform effective strategies for implementing systems thinking in science education.

The absence of responses in the 'not important' category signifies a collective agreement on the value of integrating systems thinking into the science curriculum. This positive reception aligns with the potential benefits associated with a systems thinking approach as observed by York et al.[8] This creates a supportive environment for curriculum designers, indicating that there is an endorsement for developing and implementing curriculum changes that incorporate the principles of systems thinking into science education.

The study reveals several implications based on teachers' perspectives on integrating sustainability and systems thinking principles into the science curriculum. Although the teachers agreed that sustainability issues were relevant to science and that it was important for learners to be taught about sustainability issues, the findings show that the teachers had uncertainties about ESD during the discussion interview session. This meant that their foundations for developing integrated lessons with environmental sustainability were not solid. These uncertainties could affect how they plan and conduct lessons. According to Burmeister and Eilks,[3] a positive attitude, knowledge of content, and suitable teaching strategies are requirements for infusing SD into teaching.

The open-ended questions and focus group interview exposed a discrepancy between teachers' self-reported preparedness, as indicated in closed-ended questionnaires, and their actual readiness. There was a clear mismatch of what they wrote about sustainability and the enacted, in their oral submissions. The teachers expressed varied opinions on the impact of integrated sustainability and systems thinking lessons on learners' awareness of global environmental issues and responsible citizenship.

Some oral responses that contradicted what they had indicated in the questionnaire are presented:

- *I am not sure about all this sustainability and more, the systems thinking, but could be good.*
- *We teach 'our world and our people' which looks at world issues and culture, do we need sustainability again? I mean specifically? Maybe, it should be on the timetable for emphasis.*
- *I wonder about integrating these principles. What about work load for teachers and learners?*
- *This is part of the practices and implementation of sustainable development policies, but not enshrined clearly so you wonder where to fix it sometimes. Hmmm. So much work.*

Despite differing views on the integration of these principles, all teachers unanimously agreed, even if implicitly, on the importance of teaching learners about sustainability issues. The reasons that they provided highlight a shared understanding of the critical role that learners play in environmental stewardship and the transmission of sustainability practices holistically to future generations. The teachers acknowledged challenges in their oral submissions about the incorporation of sustainability and systems thinking into their lessons, including lack of curriculum support, time constraints, resource limitations, lack of administrative support, and insufficient professional development opportunities. These challenges reflect practical barriers that need to be addressed for effective integration. According to researchers such as Jackson and Hurst,[2] York et al.[8] and Mahaffy et al.[9] effective integration processes must be put in place to attain the United Nations goals on ESD. The proposition by Hanson and Hanson[15] could be a valuable asset, if institutions could adopt or adapt the guiding principles that have been suggested for the integration of sustainability principles through the systems thinking approach.

The unanimous interest among teachers in receiving professional development on integrating sustainability principles through a systems thinking approach signigies their recognition of the need for training. The specific expectations listed, such as redesigning lessons and enhancing content knowledge, highlight the multifaceted nature of the skills they seek. While teachers expressed a need for additional resources to enhance their teaching of sustainability-embedded lessons, there was a lack of specificity regarding the required resources. The general call for 'common resources' suggests a desire for support from supervising authorities in providing the necessary tools for effective integration as found by Hanson[11].

The findings of teachers' pereptions, emphasise the complexity of views on integrating sustainability and systems thinking into science education, highlighting the need for professional development, resources, and a systemic approach. The study underscores the importance of aligning teachers' perceptions with their actual practices and addressing practical challenges to ensure effective integration of sustainability and systems thinking principles in the science curriculum.

5.1. Interpretive reflections

It is becoming clear that holistic teaching from the systems thinking approach should go beyond a focus on knowledge and skills to promote values and attitudes for sustainable development and empower responsible citizens to take action for change. Institutions should see themselves as experiential places of learning for sustainable development, and should therefore orient all their processes towards principles of sustainability from a systems thinking approach.

6. CONCLUSION

The study sought to find out teachers' perspectives on integrating sustainability and systems thinking principles into high school science curricula. The open-ended questions and focus group interview exposed a discrepancy between teachers' self-reported preparedness which was high, and their actual readiness which was low. Findings indicated that teachers perceived that they were familiar with knowledge about sustainability but not familiar with knowledge about systems thinking and its approach. Findings revealed that they were aware of topics that lent themselves to the teaching of sustainability principles. However, they intimated that they would require training in the integration of sustainability and the systems thinking approach into existing lessons. It could be deciphered from findings that an experienced teacher is not necessarily an expert teacher in emerging concepts such as the idea of and integration of the systems thinking approach in teaching practices as majority of them did not truly understand how they would integrate the new ideas into their existing lessons. Emerging concepts must be taught to practising teachers through professional development sessions to ensure that educational transformations are effective.

7. RECOMMENDATION

An important recommendation would be to organise professional development courses for teachers on new ideas that must be integrated into their lessons. Qualitative approaches are recommended to identify and understand emergent ideas and new answers provided by learners; an aspect that is crucial

to the dynamic and transformative aspects of ESD. Another recommendation would be for policy changes within schools and Departments of Science Teacher Education to support teacher development. For a start, it would be helpful if samples of integrated lessons that have sustainability issues embedded into them are made available for use by teachers, while they learn how to integrate the necessary sustainability principles into topics that would lend themselves to such from a systems thinking approach.

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