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ASSOCIATION BETWEEN UPPER-SECONDARY SCHOOL BIOLOGY CURRICULA AND TEXTBOOKS IN NIGERIA AND FINLAND – A COMPARATIVE CO-OCCURRENCE NETWORK ANALYSIS

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Abstract:
We examined the association between curriculum standards and biology textbooks from Nigeria and Finland based on the components of scientific literacy (SL), namely scientific knowledge and competences, learning contexts, and attitudes towards science. By means of content and co-occurrence network analysis we systematically determined the degree of association among the curriculum materials. The results indicate that biology curricula and textbooks from both countries overlap in terms of scientific knowledge and competences, whereas learning contexts, epistemic knowledge and attitudes towards science differ in how they relate to the other SL components. Our findings also show that a combination of content and network analysis is a useful approach to examining the association between science-curriculum standards and textbooks.

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Keywords: co-occurrence network analysis, curriculum association, scientific literacy, upper-secondary-school biology curricula, upper-secondary-school biology textbook

1. Introduction

The association existing among various educational components (i.e. curricula documents, textbooks, and assessment) is an important issue in education because within a harmonious educational system (Ziebell & Clarke, 2018), there are clear expectations about what to teach and students expected achievement (Hong *et al.*, 2019).

Association between curricular materials has been examined under titles like alignment (Yu *et al.*, 2022); curriculum coherence (Schmidt *et al.*, 2005) or relationship (Chou & Ting, 2016) using different methods. Association is the measurement of the degree of agreement between the expectations of the curriculum standards and textbooks (Schemidt & Prawat, 2006). Therefore, distinguishing between the scientific literacy (SL) contents of two biology curricula and textbooks from two different curricula traditions and socioeconomic contexts; Anglo-American in Nigeria (Nwoke *et al.*, 2022) and Bildung-Didaktik in Finland (Autio, 2014: Sjöström & Eilks, 20187) is the motivation behind this international comparative study.

In more recent years, the Programme for International Student Assessment (PISA) has been documenting the performance of students among countries of the Organization for Economic Cooperation and Development (OECD) based on SL concepts to measure their scientific knowledge and its application to everyday life's problems, and Finnish students have consistently performed well in such surveys. Thus, the complementary role of biology textbooks to the national curricula towards this success compared to other countries' efforts becomes an interesting area of investigation.

Such PISA studies help national educational systems to focus on three aspects of the curriculum: the *intended curriculum,* which is contained within national curriculum documentation, the *implemented curriculum* that is taught by teachers, and the *attained curriculum* that is learnt by students. Also, PISA studies can reveal the extent to which textbooks are a particularly vital link between the intended and attained curriculum in school science since they can help the teacher to identify knowledge and skills to be taught, instructional approach appropriate to teach them, and possible assignments for reinforcing learning. However, at the national level, there is much variation in the form of national curriculum documentation, ranging from highly specified curricula to a more flexible one with considerable local autonomy. Whatever the variation within national curricula for science, the concept of SL forms a major goal of science education (Boujaoude, 2002; Bybee, 2016).

In this study, we use the co-occurrence network analysis (CNA), a model of network analysis with a summarizing power that visually and mathematically maps the association between components of the educational environment (Kurz *et al.*, 2010). Hence, the CNA approach could be an alternative means to visualize links between upper-secondary level national biology curricula in Nigeria and Finland. Thus, this study aims to measure the association existing between two standards and textbooks based on PISA scientific literacy categories.

2. Literature review

2.1 Characterizations of scientific literacy

Scientific literacy (SL) is the conceptual word used in this study to show the association between curriculum documents and textbooks. SL has been widely used to describe the range of skills that the majority of students need to possess in an effort to facilitate future success (Choi *et al.*, 2011; Bybee, 2016). This has led to curriculum reforms in many countries with a focus on science concepts and ideas taught in secondary schools (Bartholomew *et al.*, 2002; Five *et al.*, 2014) with the potential of inculcating some essential competencies into students, such as creativity and innovation, and critical thinking which are elements of SL.

Over the years, various efforts have been made to define SL. However, there is no universally accepted definition for the concept (Laugksch, 2000; Liu, 2013). Many interest groups define it differently; for example, (National Research Council [NRC], 1996) defines it as the knowledge and understanding of scientific concepts and processes needed for personal decision-making, participating in civic and cultural affairs and economic productivity; this definition emphasizes the use of science knowledge, competencies and processing skills to be successful in daily living, while others define it in relation to science's useful application to society (Holbrook & Rannikmae, 2009).

Norris and Phillips (2003) describe scientific literacy on two essential parts: the fundamental (the abilities to speak, read and write in and about science); and the derived part which involves knowing the subject-matter (knowledge) in science and its applications. They contend that SL incorporates various components such as:

1) knowledge of the subject-matter of science and the ability to distinguish it from non-science;
2) understanding science and its applications;
3) knowledge of what counts as science;
4) ability to think scientifically;
5) ability to use scientific knowledge in problem-solving;
6) knowledge needed for intelligent participation in science-based issues;
7) understanding the nature of science;
8) appreciation of and comfort with science, including its wonders and curiosity.

On the other hand, the OECD (2007) defines SL as the extent to which an individual possesses scientific knowledge and uses it to identify questions, acquire new knowledge, explain scientific phenomena, and draw evidence-based conclusions about science-related issues.

Moreover, Birkett and Hughes (2020) posited that SL encompasses various skills related to evaluating and applying sources of information to conduct research, solve a problem or make a decision. Thus, according to (Klucevsek, 2017), SL is more than knowledge, as knowledge alone is not adequate both for students and the public; hence the need for balanced SL among learners.

2.2 Association of curricula materials

A curriculum document is seen as the road map for the attainment of national goals, as such textbooks are developed so that the contents presented in the books are in tandem with curriculum documents, without which, it is difficult to achieve national goals to the desired extent. (Saeed & Rashid, 2014). Therefore, for a nation to achieve socio-political aspirations, curriculum standards, instructional activities and supporting materials, and assessments (standardized tests) need a good degree of agreement and linkage (Anderson, 2002).

Association of curricula materials is important to the education enterprise in numerous ways; curriculum standards as policy instruments are used to articulate the vision of a subject-matter to its educational system (Schmidt *et al.*, 2005), such that what and how much students are taught is associated with, and likely influences, what and how much they learn (Anderson, 2002). Associated curricula materials become essential because through it the knowledge and skills students are expected to acquire in school are specified. Hence to facilitate the basic consistency and high standard of science education, a balance between science content and cognition should be maintained such that each textbook is consistent with curriculum standards (Yu *et al.*, 2022).

Moreover, a good curriculum association provides greater opportunities for students to learn important and useful science concepts and skills they need for future life. Thus, to achieve curriculum expectations and improve the educational system, it is necessary to ensure that textbooks incorporate the same content recommended in the curriculum (Webb, 2007). Such similar curricula structures can help in understanding international assessments of school subjects between nations (Hong *et al.*, 2019).

International comparisons can lead to curriculum reforms among nations when policymakers and school administrators take action to improve students' performances, which could result to changes in teaching strategies, classroom practices or even teacher education programs. For example, Trends in International Mathematics and Science Study (TIMSS) and PISA have influenced many countries' mathematics and science education programs, and such influence helps educators understand how students learn school science in various countries (see Hong *et al.*, 2019; Matthews & Kyi, 2019).

2.3 Past related studies between science textbooks and curriculum documents

Several studies have measured the degree of association between science curriculum standards, textbooks, and assessments by focusing on alignments (Hong & Choi, 2018; Polikoff, 2015; Sun & Li, 2021). However, it has been reported that most studies show an existing gap between science textbooks and curriculum standards (Yu *et al.*, 2022) and even between standards and assessments (Hong *et al.*, 2019; Porter, 2002). Also, Bhutto *et al.* (2022) investigated the alignment between secondary-level English textbooks and the national curriculum in Pakistan's public and private schools and reported disparities between the books due to misalignment.

In another study to examine the representation of the nature of science contents, Abd-El-Khalick *et al.* (2017) analyzed biology and physics textbooks. They reported that the textbooks did not adequately complement the requirements of the curriculum examined. Nevertheless, we employed the network analysis paradigm to reduce researchers' subjective decisions and then contributed to the methods available for measuring associations between curriculum documents and textbooks.

2.4 Contextual background

The foundation of the present-day formal education in Nigeria was laid by the activities of missionaries who set their feet on the country in the latter part of the 15th century and introduced Western formal education (Osokoya, 1987), with the primary purpose of educating the natives for Evangelization and Christianization (Oluniyi, 2013). According to Ajala *et al.* (2017), such kind of education did not meet the aspirations of the people, and the country introduced a new educational philosophy and method through a series of curriculum reforms to meet the ideals and challenges of a changing economic and social structure. Consequently, Nigeria adjusted the secondary school educational system to encompass a diversified curriculum that integrates academic with technical and vocational subjects designed to empower individuals for self-employment (see Ajala *et al.* 2017).

The country has a centralized education policy, and academic subjects include biology, chemistry, and physics, which are studied separately at the upper-secondary school level and integrated science at the junior secondary school level. Nigeria's national policy on education states the broad aim of secondary education in terms of learning outcomes (Federal Republic of Nigeria, 2004).

The new senior secondary education curricula (SSEC) including biology was developed in 2006 and implemented in 2011, and the SSEC was designed based on a thematic approach and spiral in nature, especially in content organization (Afemikhe & Imobekhai, 2014; Omosewo & Akanmu, 2013), and the aims for biology learning at this level is to prepare students to acquire: adequate laboratory and field skills, meaningful and relevant scientific knowledge, ability to apply scientific knowledge to everyday life, and reasonable and functional scientific attitude (Nigerian Educational Research and Development Council [NERDC], 2008).

On the other hand, the structure of the Finnish education system was decentralized in the 1980s, meaning that most decision-making regarding the organization and content of general education was transferred from the state to municipalities and even down to individual schools (Niemi *et al.*, 2016). The decentralized educational system implies that Finnish teachers have the autonomy and freedom to organize classes and choose content and teaching materials like textbooks (Lavonen, 2021). The Finnish curriculum has been written at two levels: the national core curriculum and the local or municipal school level; the national curriculum works as a guideline for teaching rather than a set of requirements with detailed objectives to be followed by teachers (Lavonen, 2021).

The Finnish educational system is such that there is a nine-year comprehensive and compulsory education (basic education) and a three or four-year's upper-secondary education. The purpose of science instructions at the upper level is to help students to understand the significance of science and technology as part of human culture and as a tool in modelling, predicting, and explaining natural phenomena. It also supports students' ability to participate in decision-making and problem-solving, development of interest towards science and a positive science-related self-concept (Lavonen & Reinikainen, 2014). Biology is studied as part of science education in grades one to four (FNBE, 2003). In grades five to six, it is studied under the heading 'biology and geography', while other natural sciences are studied as 'chemistry and physics.' However, in grades seven to nine and upper-secondary school, all-natural sciences, including biology, are studied as separate subjects. In Finland, the Finnish education policy strengthens biology and science education, whose prominent feature is the commitment to a vision of a knowledge-based society, educational equality, and teachers' autonomy (Lavonen, 2007). In both educational systems, textbooks are developed based on the national curricula. A good level of complementarity is expected between the two learning materials because textbooks are important links between the official national curricula and school reality (Poupova *et al.*, 2019).

2.5 Research questions

The study is therefore guided by the following research questions (RQ):

1) Using the co-occurrence network analysis, how are the scientific literacy concepts in a) National-level Nigerian biology curriculum and b) National-level Finnish biology curriculum associated with the respective upper-secondary school biology textbooks?
2) What are the similarities between the upper-secondary school biology textbooks and curricula in Nigeria and Finland in terms of the scientific literacy networks?

3. Material and Methods

The research procedures were largely made of three stages, as shown in Figure 1: 1) qualitative content analysis, 2) SL concepts extraction and matrix generation, and 3) co-occurrence network analysis (see page 156) and the materials for the study comprised of upper-secondary biology textbooks and curricula.

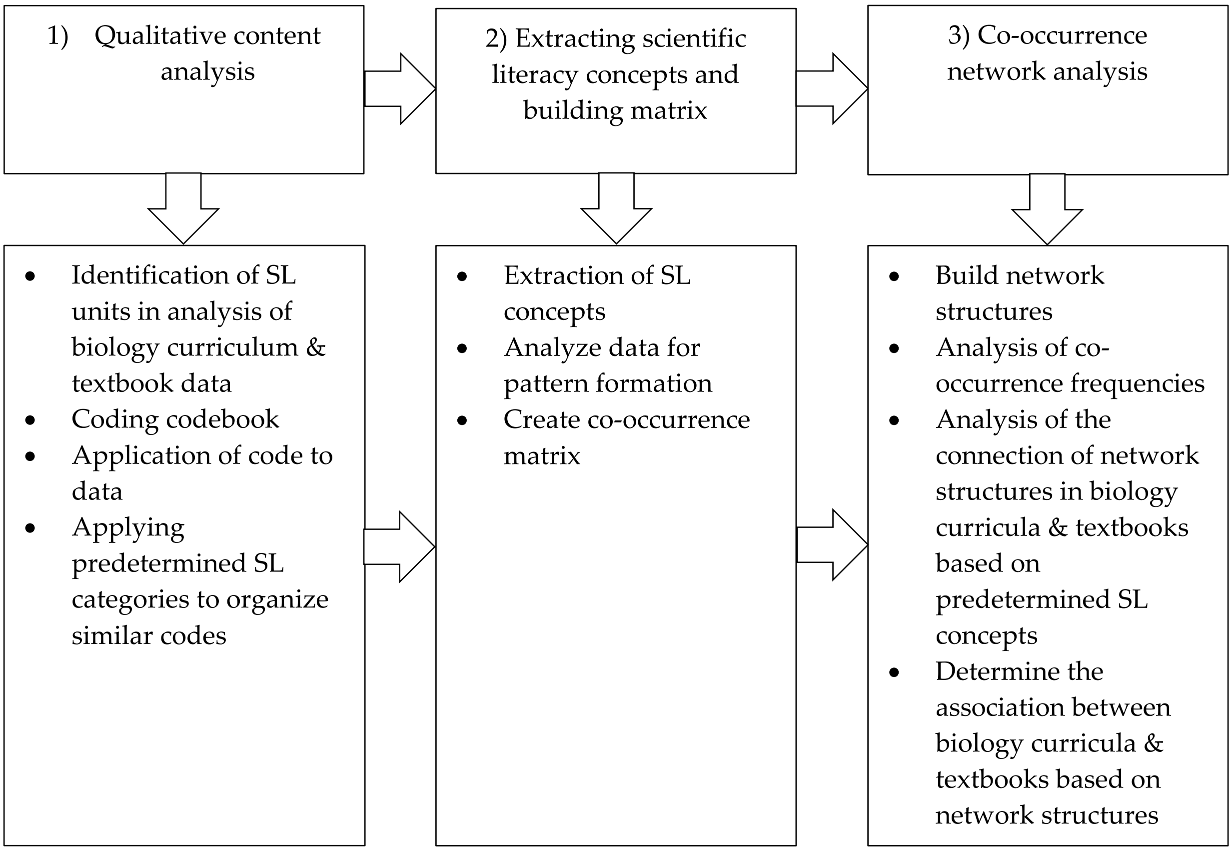

Figure 1: Flowchart of the content and network analysis processes

A modified PISA 2015 scientific literacy framework (OECD, 2016) was used as an instrument for document analysis because it refers to a combination of knowledge, skills, competencies, attitudes, and values in specific context and is useful in various problem-solving situations in adulthood (Lavonen, 2021). Thus, the framework was based on four main components of SL and 14 subcomponents (see Table 1) making it a neutral frame to compare both countries upper-secondary school biology curricula materials.

Table 1: The OECD's (2016) definition of scientific literacy components and the generated codes

OECD's (2016) SL main components	**Subcomponents**	**Codes**
Scientific knowledge is an understanding of the major facts, concepts and explanatory theories that form the basis of scientific knowledge and constitute the links that aid the understanding of related phenomena.	Content knowledge is knowledge of the basic facts, concepts, ideas and theories about the natural world that science has established.	K1
	Procedural knowledge is the awareness of the procedures used by scientists to establish what is known and the methods that technologists and engineers use to design machines; it is the awareness of the practices and concepts on which empirical enquiry is based.	K2
	Epistemic knowledge is an understanding of the role of constructs and defining features essential to the process of knowledge building in science. It includes justifying	K3

	the knowledge produced by science and its role in contributing to how we know what we know.	
Scientific competencies are the abilities to explain phenomena scientifically, evaluate and design scientific enquiry, and interpret data and evidence scientifically.	Explain phenomena scientifically, is to recognise, offer and evaluate explanations for a range of natural and technological phenomena.	C1
	Evaluate and design scientific enquiry is to describe and appraise scientific investigations and propose ways of addressing questions scientifically.	C2
	Interpret data and evidence scientifically is to analyze and evaluate data, claims and arguments in a variety of representations and draw appropriate scientific conclusions.	C3
Contexts are personal, local/national and global issues, both current and historical, that demand some understanding of science and technology.	Health and diseases deal with the health and diseases of animals and plants, social transmission of diseases, control and maintenance of health, nutrition and food choices.	CT1
	Natural resources, discusses renewable and non-renewable natural systems; conservation of natural resources; maintenance of population/ecosystems.	CT2
	Environmental quality discusses climate change/global warming; air, water and land pollution; biodiversity, variation and ecological sustainability.	CT3
	Hazards emphasize impacts of climate change, biological and chemical hazards on living thing and the environment, and the impact of modern communication on the environment.	CT4
	Frontiers of science and technology deals with the inter-relationship between science, technology and society; application of science and technology and its impacts on society; socio-scientific issues.	CT5
Attitudes are key components of a person's science competence and include a person's values, motivational orientations and sense of self-efficacy. A set of attitudes towards science are indicated by the subcomponents.	Interest in science emphasize the need for students to show curiosity in science and science-related issues and endeavors; willingness to acquire additional science knowledge and skills, using a variety of resources and methods; showing initiative and enthusiasm in planning and carrying out scientific investigation.	A1
	Valuing scientific approaches to enquiry, it encourages students to engage in enquiry-based scientific activities as a way of generating evidence for explaining the natural world and through this build's skills like open-mindedness, flexibility, critical-mindedness, creativity, and inventiveness that support problem-solving, decision-making and collaboration.	A2
	Environmental awareness refers to a concern for and responsible disposition towards the environment and its resources leading to sustainability of the earth and awareness to climate change issues.	A3

4. Analysis of the Nigerian and Finnish biology curricula materials

4.1 Qualitative content analysis

Qualitative content analysis research method (Krippendorff, 2018) was employed on two intended upper-secondary school curricula materials from Nigeria and Finland: Nigerian senior secondary school biology curriculum (NERDC, 2008) and biology textbook (Michael, 2005); and Finnish national core curriculum for upper-secondary schools: biology (FNBE, 2003) and biology textbook (Happonen, *et al.*, 2004), to generate codes applied by coders for the frequencies of predetermined SL concepts (OECD, 2016; Table 1). However, it is worthy of mentioning that the disparity in date between the Nigerian curriculum and textbook is as a result of the delay in the production of learning materials and the attendant textbook roll-over policy that has become a common feature of many Sub-Saharan African countries (UNESCO, 2014).

Content analysis is designed to identify and interpret the meaning in recorded forms of communication by isolating small pieces of data that represent salient concepts, e.g. scientific literacy and then applying a framework to organize the pieces in a way that can be used to describe or explain a phenomenon (Kleinheksel *et al.*, 2020). The materials used in this study were selected because they had existed for over ten years and will help us to project into the educational practice relating to biology curricula materials association in both countries. The data used was generated from our prior studies (Nwoke *et al.*, 2022; Nwoke *et al.*, in press) and further analyzed with a network analysis paradigm.

The guidelines for analyzing the curricula materials used in the study were adapted from a document titled 'Procedures for conducting content analysis of science textbook' (Chiappetta *et al.*, 1991b; Chippetta, Fillman, *et al.*, 2007). First, the official national-level biology curricula documents of both nations were analyzed by recognizing three comparable areas: general objectives, performance objectives and evaluation guide, while the topic 'cell' was adopted as a comparable area in the textbooks. Units of analysis were captioned diagrams, photos, pictures, tables, graphs, and charts, enquiry activities, and guiding questions. Central to this process is a content-by-SL themes representations matrix.

4.2 SL concepts extraction and matrix generation

To generate a matrix, the curriculum texts were carefully read through to determine coding units based on the study framework. Coders systematically categorized the curricula standards and textbooks into 14 SL components. Comparisons, or degree of association between the 14 SL components in each of the biology curriculum and textbook, were made by considering the amount of overlap of SL themes on the matrix through the generation of co-occurrence network structures. Secondly, tables were made at the end of the analysis to calculate the frequency of each main component and subcomponent that formed an SL idea; thereafter, the synthesized SL components in the textbook were compared to the curriculum.

To increase the validity and reliability of the study, the authors first met to discuss the analytical tools and ensure they had a common understanding of the components, which resulted in clear objectives and sentences in the coding and analysis process. Moreover, the authors made trial coding and compared the codes to test the definitions. Where agreements were not reached, they held further deliberations until an agreement was achieved, after which the authors independently coded texts of the curricula materials to ensure the reliability of the process; examples of the content analysis procedure are shown in (Table 2). Ultimately, the percentage agreement and Cohen's Kappa were calculated (Table 3).

Table 2: Examples of content analysis procedure

Scientific knowledge entity	Curricula materials texts
Content	Students to: state why the cell is a living unit (NERDC, 2008, p.4)
Procedural	Prepare an algal slide from a sample taken from the aquarium wall or cells of a water sample and observe it under a microscope (Happonen *et al.*, 2004, p. 8)
Epistemic	Be capable of assessing the opportunities, risks and ethical problems involved in the development of biotechnology and of making justified solutions based on these in their everyday lives (FNBE, 2003, p. 139)
Scientific competencies entity	
Explain phenomena scientifically	Recognise that cells require proteins, fats and carbohydrates for the production of new protoplasm, for repair, growth and provision of energy (Michael, 2005, p. 46)
Evaluate and design scientific enquiry	Know how to plan and implement a small-scale research project on the state of the environment and present the result (FNBE, 2003, p. 136)
Interpret data and evidence scientifically	Students construct and explain the pyramid of energy/number (NERDC, 2008, pp.16-17)

Table 3: Interrater reliability between two raters of the curriculum materials

Curriculum	% of agreement	Kappa
Nigeria	96	0.98
Finland	86	0.84
Biology textbooks		
Nigeria	76	0.68
Finland	96	0.96

4.3 Co-occurrence network analysis

Co-occurrence network analysis is an alternative method that uses computers to analyze the content of curricula materials by identifying links between concepts that appear together in sentences (Lou & Qiu, 2014). According to Hevey (2018), network analysis provides the capacity to estimate complex patterns of relationships, and the structure of the network can be analyzed to reveal core features. In applying the network analysis approach, we used content analysis as the basis for the co-occurrence network. First, a 2x2-contigence matrix was computed for all possible code pairs (to build the matrix). Figure 2 shows an example of a contingence matrix, where 1 indicates that the code occurred and 0 that it did not occur in a code text element. From the contingency matrix, Jaccard similarity index (S_J) is computed for the code pairs with the equation (1). The Jaccard similarity index normalizes the co-occurrences with occurrences of either code. This has the benefit of normalizing the datasets so that different-sized datasets can be compared (i.e. number of text elements).

code1

code2	1	0
1	a	b
0	c	d

$$S_J = \frac{a}{a+b+c} \quad (1)$$

Figure 2: 2x2-contingence matrix and equation for computing the Jaccard similarity index

Computing the similarity index to all possible code pairs, we get a similarity index matrix that has the index values in cells corresponding to the co-occurrence of the code pairs. This similarity index matrix can then be used as the weighted adjacency matrix of the network, where each similarity index value corresponds to the weight of the edge. Figure 3 shows a minimal example of producing a contingence matrix and computing the Jaccard similarity index from four lines of coded text elements for the code pair (K1, C1), and a similarity index matrix and the corresponding network visualization.

Text line	codes
1.	K1, C1
2.	K1, K2, K3, C2
3.	K1, C1
4.	K2, C1

C1

K1	1	0
1	2	1
0	1	0

$$S_J = \frac{2}{2+1+1} = 0.5$$

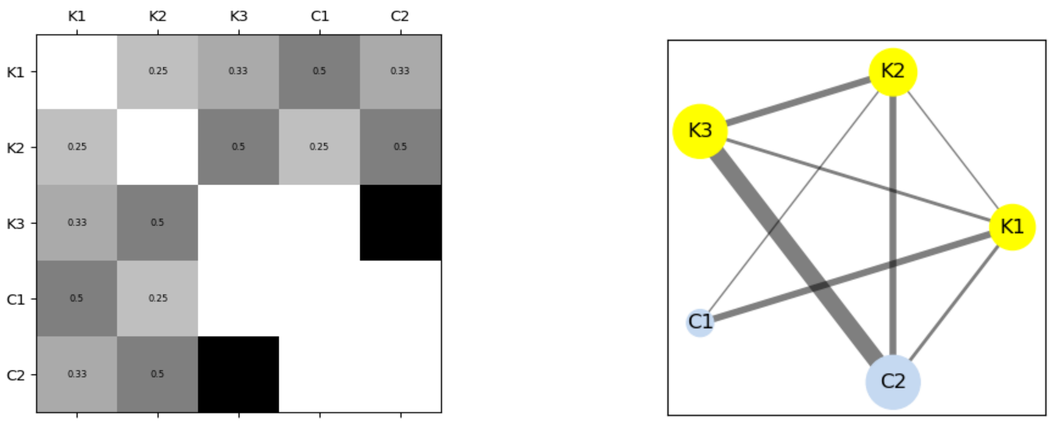

Figure 3: Example of creating and visualizing a co-occurrence network from the tabulated codes

5. Results and Discussion

The numbers of text elements from which the scientific literacy concepts were coded and the numbers of edges in the corresponding networks for each dataset are shown in Table 4. There are clear differences in the sizes of the dataset, with the Nigerian curriculum having the most text elements, whereas the Finnish curriculum has clearly the fewest. The differences in the number of edges are similarly distinct although not as major.

Table 4: Numbers of text elements in the datasets
and the numbers of edges in corresponding networks

Dataset	Text elements	Number of edges (max. 105)
Nigerian curriculum	754	79
Nigerian textbook	595	58
Finnish textbook	445	53
Finnish curriculum	131	47

Figure 4 shows that the frequencies of the codes were computed, visualized, and normalized as bar charts of scientific literacy components in the datasets. The normalization allows easier comparison between the datasets, especially as the numbers of text elements were so significant. In all datasets, the codes K1 (content knowledge) and C1 (explain phenomena scientifically) clearly occurred more frequently than the other codes. However, all codes were present in the datasets except codes CT4 (hazards) and A3 (environmental awareness) in the Nigerian and Finnish textbooks.

The width of the edges corresponds to the weight of the edges (i.e., the Jaccard similarity index), and the sizes of the nodes correspond with the node strength. Code pairs that co-occurred often are thus represented with nodes and thick edges. For example, in the Nigerian curriculum, the code pair (K1, C1) co-occurred more often than any other pair in the respective categories. Note that although the codes C1 and K1 were overrepresented in the code frequencies, they are not the only strongly co-occurred pair in any of the datasets.

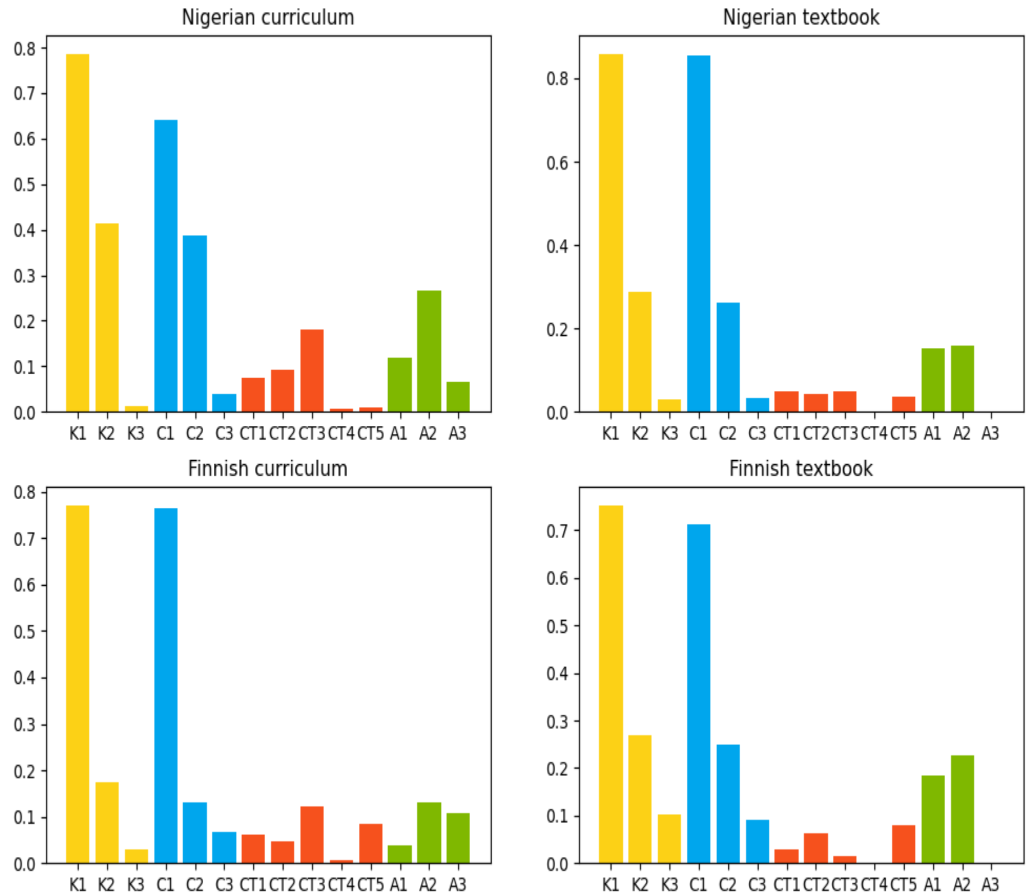

Figure 4: Normalized bar charts of the code frequencies. For SL code components, see Table 1.

The network of the Nigerian curriculum looks complete (i.e., all nodes connected with each other/maximum number of edges), but it is not a complete network since 14 nodes would have 105 edges. Also, the Nigerian and Finnish textbooks networks are missing the nodes CT4 and A3, as they did not occur in the data. However, all other codes co-occurred at least once and thus have nodes in the networks. The colors of the nodes represent the main SL components of the codes with the subcomponents as the node labels. All network computations and visualizations were done with *Python* and *NetworkX* package (Hagberg *et al.*, 2008) and a weighted Jaccard similarity index was used to compare the networks, as it is appropriate for comparing weighted undirected graphs with known nodes (Tantardini et *al.*, 2019). The weighted Jaccard coefficient accounts for both the presence and the weight of edges in the comparison of two graphs. Figure 5 shows the network visualization for each dataset (see the Table 1).

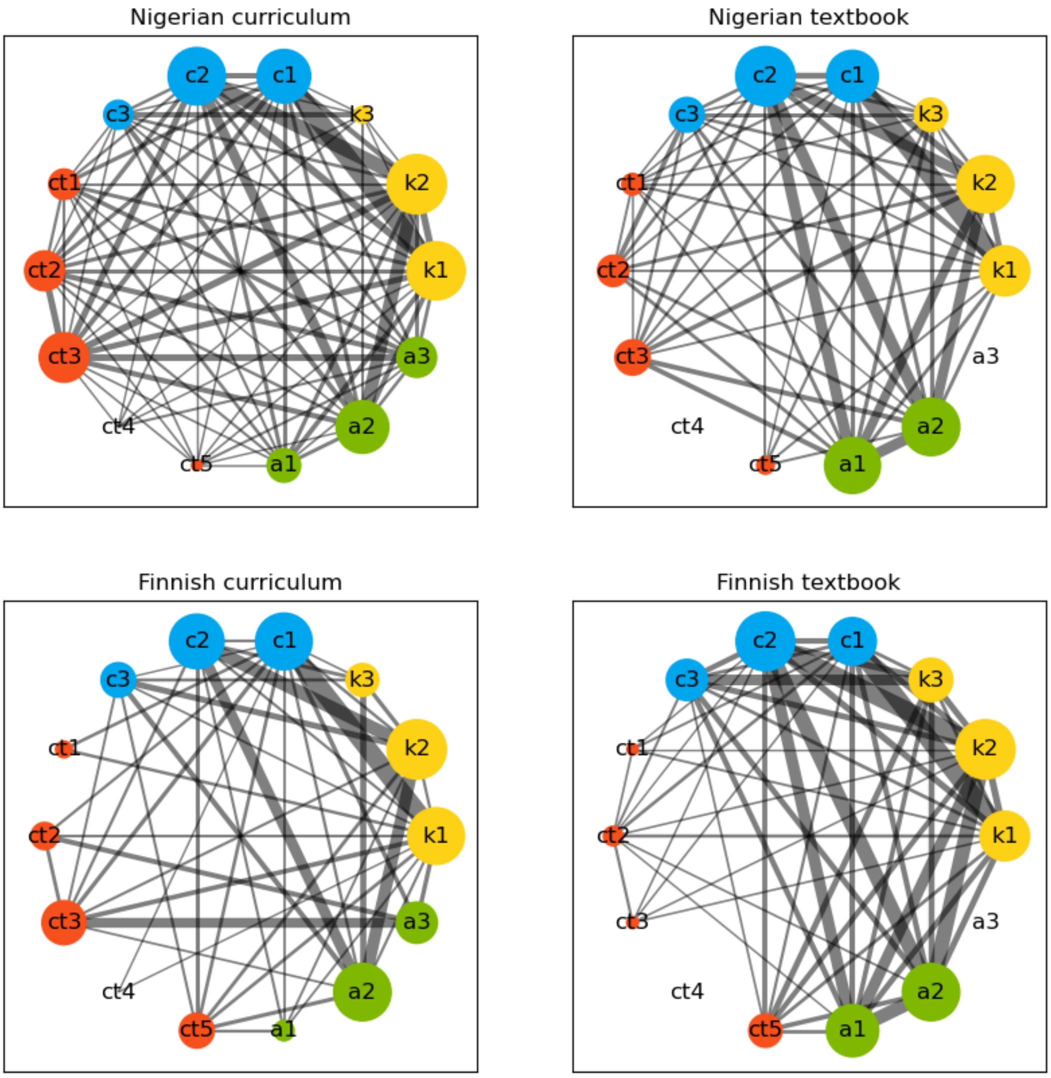

Figure 5: Network visualizations

Finally, Table 5 shows the comparison of the datasets. It includes the Spearman correlation of the code frequencies and the weighted Jaccard coefficient for network similarity. The correlation of code frequency association was quite high and showed a statistically significant association between the Nigerian biology curriculum and textbook; similarly, there was a statistically significant correlation between the Finnish biology curriculum and textbook, i.e. the two textbooks represented some of the SL themes of the curricula. More so, the weighted Jaccard coefficients shows the percentage of the network structures that overlap, i.e., exactly the same networks with the same edges and edge weights would result in value 1, but the networks are less than half similar. Hence, none of the datasets had particularly high similarity index, indicating that the networks were structurally distinct from each other. Thus, Figure 5 shows that the thick lines represent the codes that co-occurred more frequently together than separately, and this is common in the Finnish dataset than in the Nigeria dataset.

Table 5: Comparisons of the Nigerian Finnish biology curricula and textbooks datasets, showing network similarity

		Network similarity	Code occurrence frequency correlation	
Networks		Weighted Jaccard coefficient	**Spearman's ρ**	**p-value**
Nigerian curriculum	Nigerian textbook	0.49	**0.94**	<<0.001
Finnish curriculum	Finnish textbook	0.40	**0.66**	<0.05

This study analyzed the association existing between past upper-secondary school biology curriculum standards and textbooks in Nigeria and Finland, and based on RQ1, the textbooks datasets represented all the SL components of the study framework, except CT4 – hazards and A3 – environmental awareness (Figure 5) and had some levels of association. However, in comparison to the other SL components, the scientific knowledge and competencies were disproportionately associated. Additionally, when the weighted Jaccard coefficient is used to compare the similarity of the networks, it shows low similarity. Hence, if the SL cognitive range of teaching activities draws directly from curriculum objectives (as it pedagogically should), then the implication is that the materials may inadequately prepare students or disorient their expectations as they navigate the way towards the scientific literacy acquisition process (Matthews & Kyi, 2019).

The other concern arising from the Nigerian data is the heavy textual elements present in the curriculum and textbook. This may have resulted from the Anglo-American curriculum tradition that is dependent on a high-stakes assessment of the education environment in Nigeria, which requires students to show a conceptual understanding of biological concepts. Such a situation may well dissuade teachers from delivering through inquiry-based learning activities, like experiments that are known to promote conceptual development that would discourage students from memorizations (Matthews & Kyi, 2019). Our findings also show an imbalance in the coverage of the fourteen SL concepts in the Nigerian data. For example, the coverage given to epistemic knowledge (K3), interpreting data and evidence scientifically (C3), natural resources (CT2), hazards (CT4), frontiers of science and technology (CT5), and interest in science (A1) in both the curriculum and textbook are disparately low. Whether this is unintentional bias by the curriculum writers and textbook authors for these concepts is unknown, yet we see no reason why such an imbalance exists considering their importance in students' SL learning process.

In the Nigerian biology curricula materials (Figure 4), the frequency bar charts reveal different results when the SL categories are compared. The visualization of network analysis (Figure 5) shows the different connections among the SL themes and categories, K1 (content knowledge), C1 (explain phenomena scientifically), K2 (procedural knowledge), C2 (evaluate and design scientific enquiry), and A2 (valuing scientific approaches to science) are strongly emphasized more than the other categories, while the least emphasized are CT4 (hazards), CT5 (frontiers of science and technology) and K3 (epistemic knowledge). But visualization also shows that K1 (content knowledge) and C1 (explain phenomena scientifically) are the most evenly and strongly emphasized. In contrast, in the absence of CT4 (hazards) and A3 (environmental awareness), the least emphasized categories are K3, C3, CT5, CT3, CT2, and CT1. Also, in the Finnish datasets, mixed results were obtained (Figure 5). The curriculum reveals that K1 (content knowledge) and C1 (explain phenomena scientifically) are the most evenly and strongly emphasized, whereas CT4, K3 and A1 are the least emphasized. Similarly, the textbook data reveals that the most strongly emphasized SL categories are K1 (content knowledge) and C1 (explain phenomena scientifically), while in the absence of CT4 and A3, the least emphasized SL categories are CT3 and CT1; hence, showing a similar pattern with the Nigerian datasets

Thus, based on RQ2, the SL network structure of the two datasets looks similar, however, if consideration is given based on curriculum tradition, then this is a striking finding because the two nations operate different curriculum traditions (see Nwoke *et al.*, 2022) and are socioeconomically different too. Nigeria operates Anglo-American curriculum tradition and Finland a Bildung-Didaktik one; the reason for this similar network structure is not clear and would need further investigation. However, when this network is critically analyzed, the CT4 and A3 categories in the Nigerian and Finnish textbooks lack connection with the other twelve categories. Notwithstanding, the strongest and weakest links are as presented in the two country-specific dataset comparisons (Figure 5). The results suggest that similar overall SL network structure exists between upper-secondary school biology curricula and textbooks in both countries. However, based on the **Jaccard coefficient index** in Table 5, there was a notable gap between the curricula and textbooks in terms of the relationships represented by the fourteen SL concepts. The percentage of the network structures overlaps of the two country-specific datasets indicate some lack of association. This means that the textbooks did not adequately support the main SL objectives of the curricula, which supports similar past studies (see Bhutto *et al.*, 2022; Porter, 2002; Polikoff, 2015; Sun & Li, 2021; Yu *et al.*, 2022). However, one reason to the low association might be that the whole biology curricula were compared with a section of the textbook focusing only on 'cell biology'.

The argument for curricular association depends on the interconnectedness of various science concepts to form a holistic structure for students to construct deep understandings of natural phenomena and see a sense of unity in science to reduce knowledge fragmentation. Connectedness in curricula materials ensures that lessons in a science classroom have value and meaning beyond the instructional context. Consequently, making a connection to the larger contexts within which students live makes science meaningful to them (see Jin *et al.*, 2019; Roseman *et al.*, 2010; Ziebell & Clarke, 2018). According to Roseman *et al.* (2010), an associated curriculum material fosters the development of integrated understanding by students when presented with a set of related ideas and the connections among them. They further noted that to support students' learning, well-associated science textbooks should include a range of pedagogical features designed to help students build on their prior knowledge and overcome their misconceptions when applying science ideas in a variety of new contexts.

This is particularly important considering the results of the co-occurrence network analysis that showed a link between learning contexts and other SL components, which was not too impressive.

Furthermore, associated curricula materials play a pivotal role in promoting teaching and learning and help to maintain learning progression when science concepts are presented in a logically, sequenced, and balanced manner, as well as in a progressively advancing order that students can follow as they go through one grade level to another (Jin *et al.*, 2023). We argue that to promote the teaching, learning, and understanding of SL in schools, then well-associated curricula materials should be developed for all grade levels because curriculum association and related concepts like coherence can be regarded as an important determinant of students' learning in education and within science education (Schmidt *et al.*, 2005).

Finally, it is well-recognized that association in science curricula materials leads to high-quality instruction and student achievement (Fortus & Krajcik, 2012; Schmidt *et al.*, 2005). It, therefore, implies that the strength of a standards-based education system rests on the robustness of the standards since it prescribes the content deemed necessary and appropriate for students to learn and the progression through which they should learn, followed by teachers' instruction and assessment (Atuhurra & Kaffenberger, 2022).

6. Recommendations

In the future, we recommend some potential areas of research; firstly, a comparative study of upper and junior secondary schools biology curricula and textbooks with a focus on other topics beyond cell that was the subject of examination of this study should be carried out. This will enable a holistic evaluation of biology curricular materials across the secondary school levels. Secondly, such evaluation should be extended to revised curricula materials to determine the effects of such curricula on the school system and perhaps various countries' focus on current scientific issues. Thirdly, curriculum implementation through teachers' and students' interaction in the classroom should be investigated as it is capable of making countries to learn from each other and would help to improve global scientific practices.

7. Conclusion

This study has revealed the strengths and weaknesses of the Nigerian and Finnish upper-secondary school biology curricula and textbooks. We wish to emphasize that the weak areas of our findings, such as connections in the learning contexts, epistemic knowledge and attitudes towards science, should be strengthened, and overlapping areas like scientific knowledge and competencies addressed to help curriculum writers, textbook authors, and school administrators design well-associated science curricula materials.

We acknowledge that the combination of content and network analysis approach employed in this study is a useful method to examine the relationship between science curriculum standards and textbooks and can be extended to study how coherent educational systems are. We equally emphasize that careful sequencing of science concepts/topics in curricula materials should be encouraged, as it helps in the design of quality curricula and instructional resources like textbooks (Tyler, 2013) which helps to build a harmonious education system (Ziebell & Clarke, 2018). In other words, curriculum instruction and assessment are associated based not only on the logical structure and organization of the discipline but also on students' cognitive abilities of the discipline and practices (Jin *et al.*, 2023), which can result from a 'cordial relationship' between the curriculum and textbook. We add that curriculum and textbook association should be seen as a matter of disciplinary and interdisciplinary practice. Finally, we argue that a combination of associated curriculum standards and textbooks coupled with an association-oriented teaching strategy could help to forge relevant connections and coordination among SL concepts that students' study. It could also promote more effective and intelligible learning (Yeh *et al.*, 2019) linked to student achievement – (although this needs to be empirically tested).

Authors' contributions

The first author was responsible for the data acquisition and analysis, as well as drafting and writing the article. The second author was involved in methodological planning, implementation and interpretation of co-occurrence network analysis. The third and fourth authors contributed on the supervision of the theoretical and methodological issues, writing and revising the article. All authors approved the final version of the article.

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Conflict of interest statement

The authors declare no conflicts of interest.

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