sustainability

MDPI

Systematic Review

Breaking Barriers to Meaningful Learning in STEM Subjects in Africa: A Systematic Review of the Culturo-Techno-Contextual Approach

Adekunle Ibrahim Oladejo [1,*], Taibat Tejumola Olateju [2], Peter A. Okebukola [1], Rasheed Sanni [1], Hakeem Akintoye [1], Franklin Onowugbeda [3], Musa Adekunle Ayanwale [4], Deborah O. Agbanimu [5], Sakibu Saibu [3] and Umar Adam [1]

1 Africa Centre of Excellence for Innovative and Transformative STEM Education, Lagos State University, Ojo 102101, Nigeria
2 Department of Economics, Obafemi Awolowo University, Ile-Ife 220282, Nigeria
3 Natural Science Education Department, College of Science Education, Lagos State University of Education, Oto-Ijanikin 102101, Nigeria
4 Tests and measurement Unit, Department of Educational Foundations, Faculty of Education, National University of Lesotho, Maseru 100, Lesotho
5 Department of Science Education, National Open University of Nigeria, Abuja 900271, Nigeria
* Correspondence: ibrahim.oladejo@lasu.edu.ng

Abstract: Meaningful learning is central to every teaching and learning exercise. The attainment of this goal in the face of the cultural diversity of students suggests the use of culturally sensitive approaches. Several studies have shown that teachers are adopting tenets of culturally relevant education to promote meaningful learning of STEM subjects for culturally, linguistically, and socially diverse populations of learners. In Africa, the culturo-techno-contextual approach (CTCA) has witnessed great exploration in Science Technology, Engineering, and Mathematics (STEM) education to ensure students learn meaningfully. However, missing in the literature is a systematic review study on the use of CTCA in STEM teaching and learning. By synthesizing the findings of studies on the use of CTCA, this review highlights the unique contributions of CTCA to promoting meaningful learning of STEM subjects for African learners through quality research reports connecting CTCA to students' positive outcomes in science, technology, and mathematics from 2015 to 2025. Data were sought from peer-reviewed experimental studies found in Google Scholar, ResearchGate, Scopus, and Web of Science with specific selection criteria, and 24 studies were found eligible for inclusion. The findings demonstrated that CTCA has been repeatedly effective in breaking the barriers to meaningful learning of STEM subjects, helping students to understand difficult STEM concepts and improving their academic achievement. Additionally, the findings indicated several implications for practice and future research on the use of CTCA. Hence, we concluded that this review study will be a useful reference for teachers, STEM educators, and educational researchers willing to rewrite the narratives of STEM learning in Africa by decolonizing STEM education and bringing the African indigenous knowledge to the frontier of STEM teaching and learning.

Keywords: culturo-techno-contextual approach; STEM education; culturally relevant pedagogy; systematic review

check for updates

Academic Editor: Tai-Yi Yu

Received: 30 December 2024
Revised: 6 February 2025
Accepted: 26 February 2025
Published: 6 March 2025

Citation: Oladejo, A.I.; Olateju, T.T.; Okebukola, P.A.; Sanni, R.; Akintoye, H.; Onowugbeda, F.; Ayanwale, M.A.; Agbanimu, D.O.; Saibu, S.; Adam, U. Breaking Barriers to Meaningful Learning in STEM Subjects in Africa: A Systematic Review of the Culturo-Techno-Contextual Approach. *Sustainability* **2025**, *17*, 2310. https://doi.org/10.3390/su17052310

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

The dynamism of societies, technology, knowledge systems, and of learners' characteristics often inform the quest for newer and better pedagogical tools for teaching and learning

than the conventional teaching methods which continually prove insufficient [1–3]. At the same time, efforts towards achieving diversity, inclusion, and equity in STEM education elicited the development of new pedagogical approaches to effectively promote meaningful learning of STEM subjects for culturally, linguistically, and socially diverse populations of learners. With regard to this, beginning to emerge in the academic literature are pedagogies that incorporate students' cultural identities and lived experiences into classroom teaching and learning, such as culturally relevant pedagogy [4]; culturally responsive teaching [5]; and culturally congruent instruction [6] for effective instruction.

Many times, these pedagogies have proven effective in sustaining the interests of the marginalized minorities in STEM learning [7–12]. Though distinctive in some ways, these pedagogies collectively advocate for the promotion of meaningful learning using cultural and contextual referents. In Africa, one noticeable variant of the culturally relevant approaches that is being heavily explored by researchers, mostly in STEM education, is the Culturo-Techno-Contextual Approach (CTCA), invented by Peter A. Okebukola. Since its launch in 2015, quite a number of researchers have examined the potency of CTCA in improving students' learning outcomes, such as academic achievement and attitude towards STEM learning at secondary schools, as well as in bridging the gender gap in STEM learning [13–16]. In order to have a holistic understanding of the impact of the approach on students' learning outcomes, a review of studies examining its effectiveness is required.

Moreover, based on the recency of the approach, a review of the literature indicates that while there exist numerous studies on the use of CTCA to improve students' learning outcomes in STEM, a systematic review of these studies has yet to be conducted. Thus, after almost a decade of exploring CTCA in STEM classrooms, there is a clear need for evidence-based research that comprehensively documents the impact of the approach on students' learning, such that teachers, science educators, researchers, and STEM communities are well informed about the relevance of the approach, which may further inform its continuous use for the teaching of STEM subjects in ethnically diverse communities. Also, the inventor of the approach described CTCA as a tool for targeting difficult concepts in STEM subjects, and as recently as 2020, a team of researchers [17] conducted a large survey in West Africa to identify concepts in the STEM subjects' curriculum that students perceive as difficult to learn and why.

The findings of this survey suggest the need for evidence-based research targeted at tackling the perceived difficult concepts, thereby making learning more meaningful to African learners. Thus, this review will serve as a reaction update that informs teachers and researchers of areas of difficulty regarding concepts in STEM that need to be addressed. This review will also serve as a reference document to teachers with examples of cultural knowledge or practices that have been used to explain different concepts across the STEM subjects. In presenting this review, we garnered studies that examined the effect of CTCA on students' academic achievement in mathematics, ICT (Information and Communication Technology), biology, chemistry, and physics at secondary school level. Thus, the review study was guided by the following questions:

1. What difficult concepts or topics have been treated with CTCA in mathematics, ICT, biology, chemistry, and physics?
2. What impact has CTCA on students' learning outcomes in these subjects?

The Culturo-Techno-Contextual Approach is an Afrocentric pedagogy targeted at breaking barriers to meaningful learning of STEM subjects while decolonizing STEM education. As such, this study may represent our best hope to demonstrate the richness and relevance of the African cultural knowledge to enhancing scientific understanding as opposed to the supremacy of the Western knowledge, which portrays Africa as devoid

of scientific knowledge. This review may also represent a call for the re-evaluation of the traditional methods of science teaching that are mismatched to the socio-cultural realities of African learners to embracing "what works" for meaningful STEM learning in the African context.

We begin this systematic review by explaining the tenets of CTCA and how to implement the approach in the classroom. We described how we selected the studies included in the review and afterwards, we presented the findings of the review by synthesizing the studies linking CTCA to secondary school students' learning outcomes in STEM subjects. We concluded by providing implications for using CTCA to promote students' academic success and growing a robust body of research on connection of CTCA with students' positive learning outcomes in STEM education in Africa, in response to the call for diversity, inclusion, and equity in STEM learning.

1.1. The Culturo-Techno-Contextual Approach: The Implementation

CTCA emerged as a culturally and contextually flexible and adaptable approach from over 30 years of inquiry on how best to present science and other STEM subjects to African students in a way to enhance meaningful learning, bolster achievement, and sustain their interest in STEM learning. CTCA is an amalgam, drawing on the power of three frameworks: (a) the cultural context in which all learners are immersed; (b) technology mediation to which teachers and learners are increasingly dependent; and (c) locational context, which is a unique identity of every school, and which plays a strong role in the examples and local case studies for science lessons. The procedure for implementing CTCA features these three frameworks in five-step activities (see narration below).

Five-Step Implementation Procedure of CTCA

1. **Pre-lesson assignment**: This activity demands that the teacher informs the students of the topic of the coming lesson and requires the students to use social media (YouTube videos) and other topic-related web content to seek pre-lesson knowledge of the topic to be taught in class and use their understanding to reflect with their parents or any individual more knowledgeable about cultural knowledge or practices related to the topic. The students are also informed that the findings from these sources are to be shared among their peers when class activities begin.
2. **Group activities**: This step features the beginning of the main lesson. The teacher introduces the topic to the students and then groups them into mixed-sex, mixed-ability, and mixed-culture/tribe groups of a maximum of 8 to 10 members in a group, depending on the total number of students in the class. The teacher also assigns a group leader for each group. The group leaders are saddled with the responsibility of summarizing the findings (from step 1) submitted by every group member and presenting the summary to the entire class. Each presentation should last 3-5 minutes; this is to train the students in time management. After all presentations, the teacher clears all misconceptions regarding the related cultural knowledge and progresses with the lesson.
3. **Contextual examples**: This step demonstrates the context aspect of CTCA. The teacher progresses with the lesson and then refers to events, occurrences, or objects around the school environment as examples to exemplify the concepts in the topic being treated. This is accompanied by content-specific humor to make learning fun and more interesting.
4. **Cultural reflection**: The lesson is coming to an end, and the teacher needs to ensure the students have meaningful "take homes" of what was learned. So, at this point, the submitted cultural findings are reflected upon as they relate to different concepts

in the lesson. The teacher answers questions raised by the students and also asks the students some questions to ascertain their understanding of the lesson. Further clarifications are made.

5. **Lesson summary**: At the close of the lesson, the teacher summarizes the contents of the lesson. This summary will be sent to all students via a media platform created for the purpose of the lesson (WhatsApp Group). After the first lesson, the teacher will then make it the responsibility of the students' group leaders to send the lesson summary to the class upon the teacher's review. At this stage (before the class is dismissed), the students are informed about the topic or concept to be covered in the next lesson and will be asked to carry out their pre-lesson activities on the topic as performed in step 1.

   Each of these activities is straddled with different educational perspectives which form the theoretical and philosophical underpinnings of the approach.

2. The Theoretical and Philosophical Underpinnings of CTCA

In describing the tenets of CTCA, we draw upon the constructivism perspective of Vygotsky's socio-cultural learning, Ausubel's theory of advance organizer, Gay and Ladson-Billings' foundational works on culturally relevant pedagogy, and the contextualism philosophy of Kwame Nkruma. Of course, CTCA also rests on the theoretical, analytical, and philosophical strengths of many researchers, including the work of [18] on culture and contexts, philosophy of technology [19], as well as authors who reference cultural diversity or multiculturalism in science education such as [20–22]. A train of thought that connects these works is that they focus on promoting meaningful learning of science through cultural and contextual referents. However, because of the apparent overlap, the fit is swayed in favour of the Vygotsky–Ausubel frameworks and Gay–Ladson–Billings' foundational works on culturally relevant teaching. These four present well-fitting positions, guiding the use of CTCA in teaching and learning.

Vygotsky's sociocultural theory [23] asserts that learning is fundamentally a social process in which interaction with peers, parents, or any more knowledgeable other (MKO), and the wider society plays a critical role in the formation and development of higher psychological or cognitive structures of a child. Sociocultural theory also includes social interaction between the teacher and student in a school setting. The application of this theory is evident in two stages of implementing CTCA. At first, the theory is adaptive to the interactive role of parents in step 1 of implementing CTCA, providing related cultural knowledge that explains the STEM concepts. Secondly, the social interaction among students through the group discussions and classroom interactions demonstrated in step 2 of CTCA emphasizes the sociocultural perspective to meaningful learning. These interactions help the students to expand their knowledge coast beyond what they know and learn more than would be able to on their own. This represents the concept of scaffolding which is a central part of Vygotsky's theory and upon which CTCA stands. According to Vygotsky [23], scaffolding affords students the ability to learn better when collaborating with their peers or others who have a wider range of knowledge and skills than learning independently. This makes up the idea of finding out about related cultural knowledge with parents, surfing the internet for background knowledge about the concepts, and sharing knowledge in group discussions in step 1 and 2 of CTCA. Parents, technology, and the students' peers are considered the more knowledgeable other (MKO), which has been defined as not necessarily a person, but can also be a machine or book or another source of visual and/or audio information [17].

However, to ensure that students learn meaningfully through scaffolding techniques, it is extremely important that the teacher is aware of students' current knowledge level.

In Ausubel's view, this is the thrust of meaningful learning. Ausubel [24] argued that meaningful learning occurs when students are able to connect new knowledge to what they already know. The pre-lesson activities of CTCA are built upon this framework. In step 1 of CTCA, the teacher informs and prepares the mind of the students as to what is important in the incoming knowledge. This information is regarded as the advance organizer that helps the student establish baseline knowledge (what they know) and provide what is called mental scaffolding for easy and meaningful learning experiences of the new incoming material. This is the thrust of the pre-lesson activities of CTCA.

To establish the cultural relevance of the approach, we highlight Gay and Ladson-Billings' frameworks on culturally relevant teaching. The concept of culturally relevant teaching stems from the model of culturally relevant pedagogy proposed by Gloria Ladson-Billings in the early 1990s to reframe the commonly held narrative about the academic performance of students of colour. Ladson-Billings defined culturally relevant pedagogy as one "that empowers students intellectually, socially, emotionally, and politically using cultural referents to impart knowledge, skills, and attitudes" [4] (pp. 16–17). Ladson-Billings described a framework for culturally relevant pedagogy encompassing three components: academic achievement, cultural competence, and critical consciousness. She asserts that this framework does not only focus on enhancing students' academic achievement but also creating an ambience for students to accept and uphold their cultural identity while developing critical consciousness to challenge societal inequities that perpetuate their learning environment.

CTCA is deeply rooted in culture and context, emphasizing the use of the students' cultural knowledge or practices in bringing science to the learner's context. The language of science is significantly unrelated to the mother tongue which is the language of discourse in the African context. This language mismatch creates difficulty for African learners in understanding science concepts. This is a major barrier to meaningful learning of science concepts for which CTCA was designed to tackle. Hence, in congruence with Ladson-Billings' theory, the implementation of CTCA requires the teacher to assist the students to achieve academically by making their cultural practices play a key role in the understanding of science concepts. This also boosts their cultural competence, knowing that their culture is relevant to their academic success.

Gay's work focuses on teaching which centers multiethnic cultural frames of references in classroom instruction [5]. Gay defined culturally responsive teaching "as using the cultural knowledge, prior experiences, frames of reference, and performance styles of ethnically diverse students to make learning encounters more relevant to and effective for them" [5] (p. 31). She argued that students' performance on multiple measures of achievement will improve when teaching is filtered through their cultural knowledge and experiences. Placing the whole responsibility for high achievement on the teacher, Gay highlighted three key roles of a culturally responsive teacher. These are (a) teachers as cultural organizations, (b) teachers as cultural mediators, and (c) teachers as orchestrators of social contexts for learning [25] (p. 51).

These roles resonate with the responsibilities of the teacher when implementing CTCA. The teacher creates an ambience that provides opportunities for students from different ethnic backgrounds to express their cultural understandings about science concepts so that they can be incorporated and refenced in the teaching process for meaningful learning. By encouraging mixed-ethnic grouping of students (step 2 of CTCA) and clearing any cultural misconceptions about the science concepts in students' submissions (step 4 of CTCA), the teacher takes the role of a cultural mediator.

3. Materials and Methods

Although CTCA is a relatively new teaching approach explored mainly within the context of Africa, there exists a sufficient body of studies to provide insight into its effectiveness. Guided by the standards of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement [26], the reporting of this systematic review began with the selection of all relevant materials for the review study. We set specific eligibility criteria to identify research articles that are relevant to answering the review questions for inclusion and exclude studies that are ineligible for the objectives of the review (see Supplementary Materials for the PRISMA Checklist).

3.1. Eligibility Criteria

1. The study must be empirical (quantitative, qualitative, or mixed methods).
2. Given the fact that over 85% of the studies on CTCA focus on improving the performance of secondary school students in STEM subjects, the population of the studies included for review must be secondary school students.
3. Peer-reviewed journal articles and conference papers were included. Due to the novelty of the approach, most of the innovative research using CTCA were documented in conference papers. However, we chose only peer-reviewed journal articles and conference papers to ensure that only studies which have been peer-reviewed were included.
4. Since CTCA was officially launched in 2015, we captured studies published from 2015 to 2025.
5. For transparency and replicability of this review, articles for inclusion must be downloadable full text; restricted articles such as abstracts only were excluded.
6. Included articles must compare CTCA (in an onsite or online classroom) with other teaching methods.
7. The study connects CTCA with students' performance in STEM subjects.

3.2. Databases and Included Studies

On 16 September 2024, we searched through four international databases, Google Scholar, ResearchGate, Scopus, and Web of Science, using the term "culturo-techno-contextual approach" to find peer-reviewed journal articles and conference papers published between 2015 and 2024 for this review. This process was repeated in January 2025 to capture any recent studies on CTCA. These databases contain the majority of accessible (downloadable full text) peer-reviewed studies, including ones that were not published in open access; thus, we argued that their combination provides optimal search methods that guarantee adequate coverage. On Google Scholar, we defined our advanced search to include articles with all the words, with the exact phrase of culturo-techno contextual approach, and to find the phrase anywhere it appears in the articles rather than only in the title. This search generated 91 results. The search on Scopus generated 22 articles, and we had 51 and 16 results from ResearchGate and Web of Science, respectively. This means that 180 studies were retrieved from these databases. For the 180 studies, we did title and author match to remove duplicates from the results. We found that 86 studies obtained from the sources were duplicates and thus removed. Also, 3 studies which represent duplicates of conference papers converted to journal articles were removed. This resulted in 91 studies that were retrieved for further assessment.

Our further selection of the retrieved articles was based on the eligibility criteria to minimize the chance of including non-relevant studies. We sorted through the abstracts to find articles that fit into the eligibility criteria and were suitable for answering the review questions. This task was carried out by three reviewers working independently to reduce the chance of error and increase the credibility of our selection process. This is

in line with the recommendation in [26]: "mostly, the quality with three reviewers would be better than two, as two only would have different opinions from each other, so they cannot decide, while the third opinion is crucial" [27] (p. 5). While reading through the abstract, we focused on studies reporting the impact of CTCA on secondary school students' learning outcomes in terms of academic achievement and other measures of students' success. We excluded 5 studies using participants from a higher education level like universities, polytechnics, or colleges of education. These 5 studies were also found to focus on concepts in the humanities rather than STEM concepts and thus were excluded due to failing two eligibility criteria. Studies that only described what CTCA is or discussed how to implement CTCA in the classroom (23 studies) were excluded. This left us with 63 studies for full-text screening.

After the abstracts had been selected, we embarked on full-text reading. Similarly, three reviewers worked independently to decide which articles represent our review objectives. At the beginning of the reading, three studies for which the full text were not available (abstract only) for screening were excluded. Our interest in quality research reports is reflected in the inclusion of only peer-reviewed journal articles and peer-reviewed conference papers. Hence, non-peer-reviewed articles or conference papers (11) that were found during the full-text screening were excluded, and we had 49 studies left to work with. We further engaged in a manual search that involved searching through the reference lists of the collected articles to find similar studies that may have been overlooked in the initial search. This search generated 19 studies; however, they were already included in our previous search, parts of which have been excluded, and the other parts were included in the remaining 49 studies.

It is worth noting that a large body of research connecting CTCA to students' learning outcomes have been conducted and still ongoing as undergraduate projects, master's dissertations, and doctoral theses at Lagos State University Africa Centre of Excellence for Innovative and Transformative STEM Education (LASU-ACEITSE). However, many of these studies are not accessible online as they remain shelved. Those we found during our full-text reading (29 studies) brought about disagreements among the three reviewers. One of the reviewers, against the other two, was of the opinion that these studies should have been included in the review; however, given the reviewers' knowledge of other inaccessible studies in this category, it was decided that including those studies would have amounted to biased selection of studies. Also, because the studies were not peer-reviewed and might not reflect our interest in peer-reviewed research reports, through discussion among the authors, it was agreed to exclude those studies, reflecting our diligence to unbiased selection of articles. This left us with 20 studies for review synthesis.

As of 26 January 2025, we have received notifications from Scopus as well as Google Scholar regarding four new publications on CTCA. These studies were included after being assessed for the eligibility criteria. Working with 24 studies, we acknowledge that no research review is exhaustive, and we assume that we have reviewed and synthesized a sufficient body of research to address the objectives of this study, support the implications provided in our discussion, and to serve as a footing for others willing to bring about significant improvements in students' learning (see Figure 1 for a schematic overview of the search, inclusion, and exclusion process).

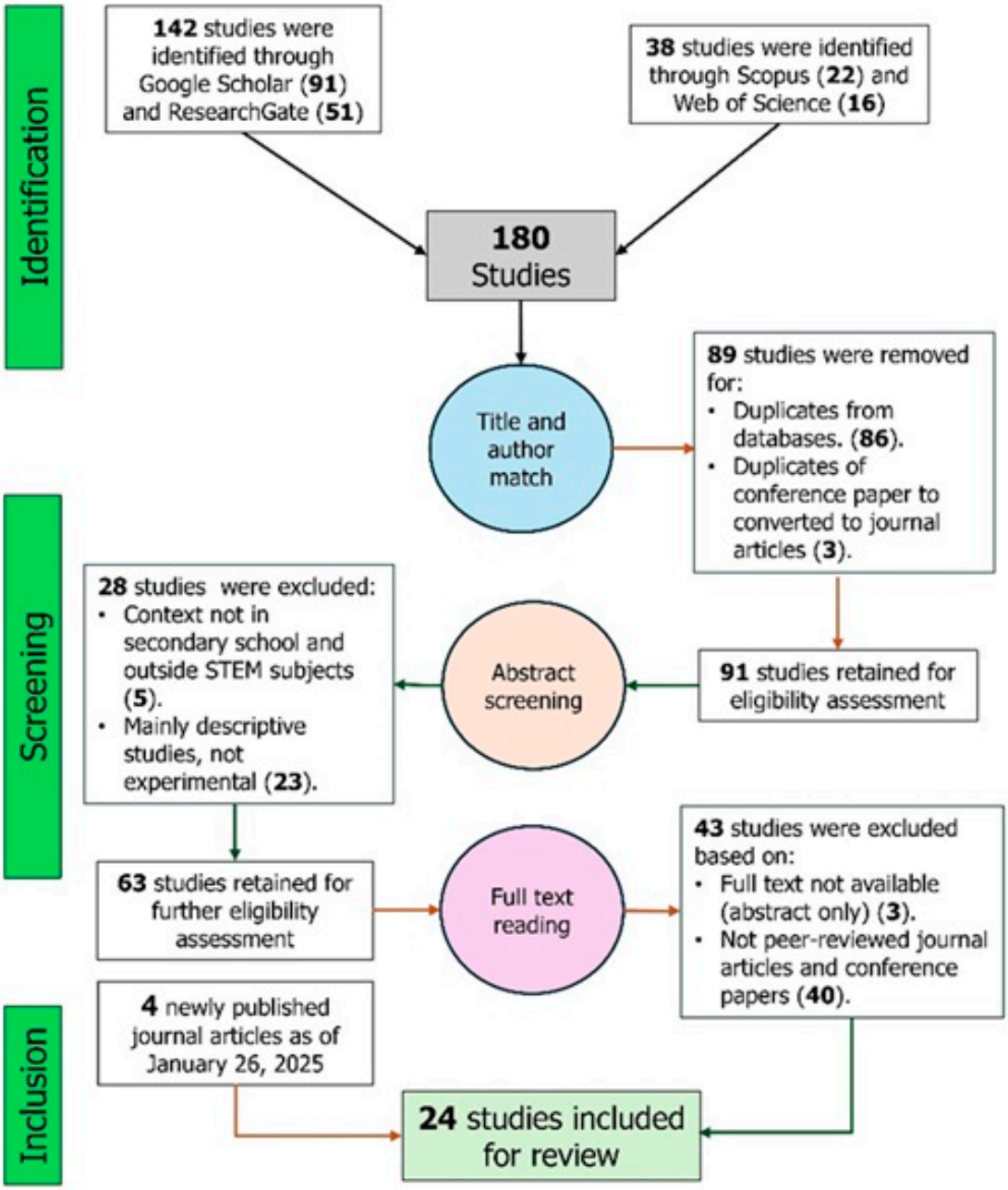

Figure 1. PRISMA flow diagram.

4. Results

4.1. RQ1: What Difficult Concepts or Topics Have Been Treated with CTCA in Mathematics, ICT, Biology, Chemistry, and Physics?

The studies reviewed indicated that five STEM subjects have been explored, including biology, chemistry, physics, mathematics, and ICT. Table 1 provides an overview of the difficult concepts which CTCA has addressed. From the 24 studies that emerged (as seen in Table 1), the majority of the studies explored CTCA in ICT (n = 8) and biology (n = 6) concepts (variation and evolution were repeatedly covered using different research objectives). Less frequently explored STEM contents in the reviewed studies are mathematics and physics concepts.

Table 1. An overview of the STEM concepts treated with CTCA.

STEM Subjects/Difficult Concept	Reviewed Studies	Educational Level
Biology/Ecology	Study 1	Senior secondary school II
Biology/Cell Division	Study 2	Senior secondary school II
Biology/Variation and Evolution	Study 3, 4 and 5	Senior secondary school II
Biology/Genetics	Study 6	Senior secondary school II
Biology/Tissue and Supporting System	Study 7	Senior secondary school II
Biology/Nutrition	Study 8	Senior secondary school II
Chemistry/Nuclear Chemistry	Study 9 and 10	Senior secondary school II
Chemistry/Electrochemistry	Study 11, 12 and 13	Senior secondary school II
Physics/Refractive Indices	Study 14	Senior secondary school I
Mathematics/Set Theory	Study 15	Senior secondary school I
ICT/Spreadsheets	Study 16	Junior secondary school III
ICT/Machine Language	Study 17	Senior secondary school II
ICT/Python Programming	Study 18	Senior secondary school II
ICT/Logic Gate	Study 19	Junior secondary school II
ICT/Program Development Circle	Study 20, 21	Senior secondary school II
ICT/Computer Networking	Study 22	Junior secondary school I
ICT/Flowcharts and Algorithms	Study 23	Junior secondary school III
ICT/Windows Interface	Study 24	Sixth grade

Regarding the educational level associated with the teaching concepts, the reviewed studies show that CTCA has largely been used to teach STEM concepts at senior secondary school. Very few studies (n = 4), only in the context of ICT, explored concepts taught at the junior secondary school level. This suggests that CTCA is adaptable to teaching STEM concepts at any educational level.

4.2. RQ2: What Impact Has CTCA on Students' Learning Outcomes in These Subjects?

In this section, we synthesize the impact of CTCA on students' learning outcomes as reported in the reviewed studies. The review of all selected studies reveals some similar and differential findings with regard to this objective. In measuring the impact of CTCA, the common evaluation technique was a quantitative approach (n = 16), involving a quasi-experiment. A few of the studies utilized a mixed-method design (n = 8), and none of the studies employed only a qualitative design. Achievement test scores were the primary source of the quantitative data using a control and experimental group in the pre-test and post-test design, while the qualitative data were obtained from in-depth interviews of the students. With the understanding that academic success is more than what an achievement test can measure, the mixed-method studies, although limited, provide us with a better understanding of the findings as we are able to triangulate the quantitative results with the qualitative findings.

Based on the nature of their impact on students' learning outcomes, the reviewed studies are subcategorized under three subsections indicating their impact on (i) students' academic achievement, (ii) students' critical thinking skills, and (iii) students' learning experience. These subsections clearly represent what CTCA has achieved in reviewed years (2015 to early 2025).

4.2.1. Impact on Students' Academic Achievement

It is worth noting that improving students' academic achievement has majorly been the research objective of the studies applying CTCA to teaching and learning STEM subjects, as indicated by the report of reviewed studies (n = 22). These studies explored the impact of CTCA on students' academic achievement using pre-test and post-test evaluation techniques (see Table 2) and found that CTCA has positive impact on students' academic achievement in comparison with the placebo treatment (traditional lecture method). These findings indicate that students taught perceived difficult concepts in STEM using CTCA gain better understanding of the concepts and thereby achieve higher academic achievement in the learning objectives of the concepts.

Table 2. Summaries of studies that reported impact on students' academic achievement.

Reviewed Studies with Title	Purpose	Method	Findings Regarding the Impact on Academic Achievement
Study 1 Improving the Achievement of Secondary School Students: How can CTCA help in Ecology?	To determine the topics/concepts in the secondary school biology curriculum students find difficult to learn and then explore the potency of CTCA in ensuring meaningful learning of ecology	Survey of difficult concepts; quasi-experimental study; pre- and post-test; n = 79	A statistically significant difference in the academic achievement of students in the experimental (CTCA) and control group
Study 2 Exploratory study of the efficacy of the Culturo-Techno-Contextual Approach (CTCA) in students' understanding of biology	To test the potency of the culturo-techno-contextual approach (CTCA) in enhancing students' understanding of cell division	Quasi-experimental; pre-test and post-test non-equivalent group; n = 47	The experimental (CTCA) group (mean = 33.29 and SD = 2.37) significantly outperformed the control (lecture) group (mean = 23.19 and SD = 4.92) in cell division [$F(1, 44) = 137.19$; $p < 0.05$]
Study 3 Can the culturo-techno-contextual approach (CTCA) promote students' meaningful learning of concepts in variation and evolution?	To investigate if the use of CTCA as an intervention will enhance students' performance in variation and evolution concepts in biology	Quasi-experimental; pre-test, post-test non-equivalent group; n = 156	Students in the experimental group who were taught variation and evolution using CTCA performed significantly better $F(1, 134) = 15.40$; $p < 0.01$] than their control group counterparts
Study 4 Reducing anxiety and promoting meaningful learning of biology concepts through a culturally sensitive and context-specific instructional method	To examine the influence of CTCA in fostering meaningful learning of difficult biology concepts and lowering student anxiety	Quasi-experimental; pre-test and post-test non-equivalent group; n = 88	The experimental (CTCA) group demonstrated significantly improved achievement [$F(1, 85) = 58.81$; $p < 0.01$] compared to the other group and a substantial difference was found between the pre-test and post-test of the experimental group

Table 2. *Cont.*

Reviewed Studies with Title	Purpose	Method	Findings Regarding the Impact on Academic Achievement
Study 5 A cultural, technological, and contextual pedagogy to enhance retention of biology concepts	To examine the impact of CTCA on promoting knowledge retention of biology concepts	Quasi-experimental; pre-test and post-test non-equivalent group; n = 88	Students taught using CTCA (experimental group) had significantly higher learning achievements than the control group who were taught using the lecture method
Study 6 A beautiful garment from old fabrics: the analogy of culturo-techno-contextual approach for meaningful learning in science.	To break the barriers to meaningful learning of genetics which is perceived as a difficult concept in biology	Explanatory sequential design (quasi-experimental and interviews); n = 124	There was a substantial improvement in students' understanding of genetics concepts when taught with CTCA (M= 24.58) compared to the lecture method (M= 16.83); [F(1, 121) = 58.06; $p < 0.01$]
Study 7 The potency of culture, technology, and context in a biology classroom: Culturo-Techno-Contextual Approach in action.	To investigate the efficacy of CTCA as an intervention in enhancing the knowledge retention of secondary school students in biology	Quasi-experimental (pre-test post-test non-equivalent group) design; n = 103	Students taught using the culturo-techno-contextual approach had a higher knowledge retention ability and thus achieved higher than those in the comparison group
Study 9 In search of culturally responsive tools for meaningful learning of chemistry in Africa: We stumbled on the culturo-techno-contextual approach	To improve secondary school students' academic achievement in nuclear chemistry	Quasi-experimental; pre-test, post-test non-equivalent group design; n = 221	CTCA had a significant effect on students' learning and meaningful understanding of the concept with a partial eta squared size of 60%
Study 10 Impact of culturo-techno-contextual approach (CTCA) on learning retention: A study on nuclear chemistry	To find out the difference in knowledge retention of students taught nuclear chemistry using the CTCA and lectures	Mixed methods; pre- and post-test; students' interviews; n = 91	There was a significant difference in the achievement of the students in the control and the experimental groups [F(1, 88) = 263.06; p = 0.00]
Study 11 Ways to Learning Science are Undergoing Mutation: Would the Culturo-Techno-Contextual Approach be an Effective Variant for Learning Chemistry?	To improve students' academic achievement in electrochemistry	Mixed-method (explanatory sequential) design; quasi-experimental; interviews on students' perception; n = 141	Students taught with CTCA gained meaningful understanding of the concept and thus achieved significantly higher than the students taught with the lecture method
Study 12 Beyond Achievement of African Secondary School Students in Chemistry: Critical Thinking in Focus	To enhance the learning achievement and critical thinking ability of the students in chemistry contents using cultural practices.	Mixed-method (explanatory sequential) design; quasi-experimental; interviews on students' perception; n = 141	A statistically significant difference [F = 55.92; $p < 0.05$] between the control (M = 9.85) and experimental (M= 16.19) groups in favor of the latter

Table 2. *Cont.*

Reviewed Studies with Title	Purpose	Method	Findings Regarding the Impact on Academic Achievement
Study 13 Face-to-Face and blended: Two pedagogical conditions for testing the efficacy of the culturo-techno-contextual approach on learning anxiety and achievement in chemistry	To reduce learning anxiety and promote meaningful learning of chemistry concepts in face-to-face and blended learning mode	Mixed-method (explanatory sequential) design; quasi-experimental; interviews on students' perception; n = 141	CTCA face-to-face group performed significantly better than CTCA blended group and the control group [F(2, 136) = 72.05; $p < 0.01$]
Study 14 Changing the Narratives of Physics-Learning in Secondary Schools: The Role of Culture, Technology, and Locational Context	To determine the topics/concepts in the secondary school physics curriculum students find difficult to learn and then explore the potency of CTCA in breaking the barriers to learning of refractive indices	Survey; quasi-experimental; interviews on students' perception; n = 1621; n = 205	No significant difference between the groups (CTCA and lecture method) at the entry level (pretest scores, $p = 0.76$). Ater being taught with CTCA, the experimental group significantly outperformed (F(1, 202) = 64.48; $p < 0.01$) the control group
Study 15 The convergence of culture, technology and context: A pathway to reducing Mathophobia and improving achievement in mathematics.	To explore the potency of CTCA in reducing math anxiety and promoting meaningful learning of mathematics among secondary school students	Mixed-method (explanatory sequential) design; quasi-experimental and individual students' interviews; n = 208	CTCA enhanced learning achievement [Pillai's Trace = 0.34 (F = 53.09; $p < 0.01$)] more effectively than the traditional teaching method
Study 16 The culturo-techno-contextual approach and students' understanding of computer science education in a developing economy	To compare the effectiveness of CTCA with the lecture method in the teaching of computer science education	Quasi-experimental; pre-test, post-test non-equivalent group design; n = 65	The experimental group significantly outperformed the control group [F(1, 60) 5 41.89; $p < 0.05$], indicating CTCA is a viable intervention in improving students' performance in spreadsheets
Study 17 Ok I need help! Can CTCA rescue Teaching and Learning Machine Language in an African secondary school?	To compare the effectiveness of CTCA with the lecture method in enhancing knowledge retention of students in machine language	Quasi-experimental; pre-test, post-test non-equivalent group design; n = 137	A statistically significant difference in method of teaching [F(1, 137) = 111.61; $p < 0.05$]
Study 18 I am a cultural teaching method-I was Successful in the ICT Class in the Global South.	To investigate the efficacy of CTCA in understanding Python programming in the Nigerian computer science education curriculum	Quasi-experimental; pre-test, post-test non-equivalent group design; n = 94	A statistically significant difference in the achievement of students taught Python programming using CTCA and the lecture method [F(1.89) = 16.89; $p < 0.05$]

Table 2. *Cont.*

Reviewed Studies with Title	Purpose	Method	Findings Regarding the Impact on Academic Achievement
Study 19 Reducing Underachievement and Promoting Critical Thinking Skills in Computer Studies Through a Culturally Sensitive Instructional Method.	To reduce underachievement in learning ICT concepts and enhance critical thinking skills of students using CTCA and Gbeleyi 1.0	Survey of difficult concepts in computer studies; explanatory sequential design; pre-test, post-test non-equivalent group design; interviews; n = 213	The use of related cultural knowledge helps the students to easily understand the ICT concepts and hence achieve higher than their comparison groups (Gbeleyi 1.0 and lecture method)
Study 20 Culturally Relevant Pedagogies in Enhancing Students Learning of ICT Concepts: A Test of the Efficacy of CTCA	To improve students' achievement in computer studies	Quasi-experimental research; pre-test and post-test non-equivalent group design; n = 217	CTCA promotes meaningful learning of ICT concepts among secondary school students in Nigeria as the experimental group significantly outperformed the comparison group
Study 21 Fostering positive instruction of software development cycle through a culturally responsive pedagogy	To investigate the effectiveness of a culturally responsive pedagogy (CTCA) in improving students' meaningful learning of the software development cycle	Quasi-experimental; pre-test, post-test non-equivalent group design; n = 127	A statistically significant difference in the students' achievement [$F(1, 136) = 172.13$; $p < 0.05$]
Study 22 Exploring the Potency of Culturo-Techno-Contextual Approach on Achievement of Secondary School Students in Computer Networking	To address the poor achievement of senior secondary school students in computer studies in Nigeria	Quasi-experimental; pre-test, post-test non-equivalent group design; n = 47	There is a statistically significant difference in the achievement of students taught computer networking using CTCA and the lecture method
Study 23 Mitigating difficulty in Computer studies through Culturo-Techno-Contextual Approach	To investigate the effectiveness of a CTCA in teaching flowcharts and algorithms to junior secondary school students	Quasi-experimental; pre-test, post-test non-equivalent group design; n = 196	Through cultural knowledge and creative instructional materials, CTCA promotes meaningful learning and enhances students' performance in computer studies
Study 24 Teaching ICT to pre-schoolers in the global south using indigenous knowledge patterns	To address the challenges of limited access to technology and gender inequality in Ghana's education system	Quantitative approach; quasi-experimental; n = 120	CTCA improved students' understanding of ICT without ICT resources

For example, study 3 investigated if the use of CTCA would enhance students' achievement in the concepts perceived as most difficult in the biology curriculum—variation and evolution—and found that connecting the biology concepts to students' cultural knowledge and practices helped CTCA group (M = 20.18) achieve significantly higher achievement than their control (M = 16.08) counterparts [$F(1, 154) = 15.40$; $p = 0.00$]. In the same vein, studies 9, 10, 14, 15, and 6 (see Table 2) demonstrated the significant impact of CTCA in

improving students' achievement in chemistry, physics, mathematics, and other biology concepts perceived as difficult using delayed post-test scores. The studies reported that because CTCA ensures meaningful understanding of difficult concepts by using cultural references and contextual examples to exemplify the concepts, the students were able to retain the knowledge gained for a longer period of time; hence, their performance improved during assessment.

These findings emphasize the unique contributions of the cultural and contextual aspects of CTCA, stressing that meaningful learning of science concepts occurs when students can integrate the knowledge into their cultural practices or daily activities.

4.2.2. Impact on Students' Critical Thinking Skills

Beyond the measure of students' achievement in tests and examinations, three studies reported a positive impact of CTCA on students' critical thinking skills (see Table 3). The COVID pandemic was about the most recent reminder that the world's knowledge of science is not yet at its best and that the world truly needs more scientifically oriented citizens who can think critically to solve our societal problems. Thus, the need to shift the gaze of research to other determinants of quality education such as critical thinking skills, problem solving skills, and creative thinking becomes paramount. In response to this need, study 12 and study 8 investigated how CTCA can instigate and enhance the critical thinking skills of secondary school students in chemistry and biology concepts, while study 19 experimented with junior secondary school students in ICT concepts. The three studies used pre-test and post-test comparison between the experimental (CTCA) group and the control group to demonstrate the impact on students' critical thinking skills.

Table 3. Summaries of studies that reported impact on students' critical thinking skills.

Reviewed Studies with Title	Purpose	Method	Findings Regarding Impact on Students' Critical Thinking Skills
Study 8 Bridging culture and science: Culturo-Techno-Contextual Approach in culturally relevant biology pedagogy.	To enhance the critical thinking ability of the students in biology contents	Explanatory sequential design; pre-test, post-test non-equivalent group design; interviews; $n = 121$	A significant improvement in critical thinking skill of CTCA group ($F(1, 198) = 11.43$; $p < 0.05$) in comparison to the control group
Study 19 Reducing Underachievement and Promoting Critical Thinking Skills in Computer Studies Through a Culturally Sensitive Instructional Method.	To promote critical thinking skills of students with CTCA and Gbeleyi 1.0	Survey of difficult concepts in computer science; explanatory sequential design; pre-test, post-test non-equivalent group design; interviews; $n = 213$	CTCA enhances the critical thinking skills of the students with a significant difference between the experimental and groups [$F(2, 208) = 15.14$; $p < 0.05$]
Study 12 Beyond Achievement of African Secondary School Students in Chemistry: Critical Thinking in Focus.	To explore the potency of CTCA in promoting the critical thinking skills of chemistry students using cultural practices embedded in electrochemistry concepts	Explanatory sequential design; pre-test and post-test non-equivalent group; in-depth interviews on students' perception; $n = 141$	The pre-lesson activities play instrumental role in enhancing the students' critical thinking

While there are unresolved concerns regarding the difficulty in teaching and measuring critical thinking skills especially, when the teaching approach (teacher-centered

approach) does not support its infusion into teaching and learning activities, researchers rely on the tenets of CTCA to awaken the critical consciousness of students. Using real-life narrations and experiences, study 12 engaged the students in culturally and contextually sensitive discussions that explain the concepts in electrochemistry. This helped to concretize the students' understanding and reasoning. Also, through a critical thinking test, designed using real-life events relating to concepts in electrochemistry, the critical thinking skills of the students were assessed and CTCA was found to have a positive impact compared to the lecture method. Qualitative data obtained through the students' interviews corroborate the quantitative findings, indicating that the cultural and contextual activities of the approach enhanced the critical thinking ability of the students; particularly, it was noted that the reflection on relevant cultural knowledge which features in step 1 of CTCA was instrumental in developing and enhancing the students' critical thinking skills, as this task involves some form of deep thinking and sense-making of the science concepts.

4.2.3. Impacts on Students' Learning Experience

In the reviewed studies, eight studies provided empirical evidence related to the students' learning experiences while exploring the effectiveness of CTCA in STEM subjects (see Table 4). These studies employed a validated interview guide and anxiety scale to gather a broad idea of how students in the experimental group perceived their experience in terms of learning engagement, enjoyment, and motivation when taught using CTCA. In most cases, the findings of these studies were targeted towards corroborating the statistical evidence of the effectiveness of CTCA in improving students' learning achievement. In a few cases (n = 3), determining the effects on learning experiences (anxiety reduction) was the main research objective, hence providing statistical evidence of attributing the impact on learning experiences to the unique features of CTCA.

Table 4. Summaries of all studies that reported impact on students' learning experiences.

Reviewd Studies with Title	Purpose	Method	Findings Regarding the Impact on Learning Experiences
Study 6 A beautiful garment from old fabrics: the analogy of culturo-techno-contextual approach for meaningful learning in science.	To break the barriers to meaningful learning of genetics which is perceived as a difficult concept in biology	Explanatory sequential design (quasi-experimental and interviews); n = 124	Most students reported to have enjoyed learning with CTCA as it helps them to quickly recall what was learnt and increases their active engagement in class
Study 11 Ways to Learning Science are Undergoing Mutation: Would the Culturo-Techno-Contextual Approach be an Effective)	To improve students' academic achievement in electrochemistry	Mixed-method (explanatory sequential) design; quasi-experimental; interviews on students' perception; n = 141	Students consider CTCA a better approach to learning chemistry and also confirmed that it aided their understanding of the electrochemistry concepts taught in class. The majority of the interviewees considered cultural knowledge, YouTube videos, and class group activities as the most impactful aspects of the approach

Table 4. *Cont.*

Reviewd Studies with Title	Purpose	Method	Findings Regarding the Impact on Learning Experiences
Study 10 Impact of culturo-techno-contextual approach (CTCA) on learning retention: A study on nuclear chemistry	To find out the difference in knowledge retention of students taught nuclear chemistry using the CTCA and lectures	Mixed methods; pre- and post-test; students' interviews; n = 91	Besides making lessons easier and interesting, students also expressed willingness to be taught other science concepts with CTCA
Study 12 Beyond Achievement of African Secondary School Students in Chemistry: Critical Thinking in Focus.	To enhance the learning achievement and critical thinking ability of the students in chemistry contents using cultural practices	Mixed-method (explanatory sequential) design; quasi-experimental; interviews on students' perception; n = 141	Every aspect of CTCA played significant roles in making the lessons enjoyable. Students expressed excitement in their learning and wished they continued to be taught with the approach
Study 13 Face-to-Face and blended: Two pedagogical conditions for testing the efficacy of the culturo-techno-contextual approach on learning anxiety and achievement in chemistry	To reduce learning anxiety and promote meaningful learning of chemistry concepts in face-to-face and blended learning mode	Mixed-method (explanatory sequential) design; quasi-experimental; interviews on students' perception; n = 141	The summary of findings from the students' responses indicated that the students considered the group discussions and presentations, humor and contextual examples, as well as the summary of lessons a remarkable experience and, thus, concretized their understanding of the concept
Study 14 Changing the Narratives of Physics-Learning in Secondary Schools: The Role of Culture, Technology, and Locational Context	To determine the topics/concepts in the secondary school physics curriculum students find difficult to learn and then explore the potency of CTCA in breaking the barriers to learning of refractive indices	Survey; explanatory sequential design; quasi-experimental; interviews on students' perception; n = 1621; n = 205	Students found the interactive activities in CTCA classroom very interesting and engaging. An excerpt from the responses reads: "I found the group activities more interesting because I gained more knowledge from other people"
Study 15 The convergence of culture, technology and context: A pathway to reducing Mathophobia and improving achievement in mathematics.	To explore the potency of CTCA in reducing math anxiety and promoting meaningful learning of mathematics among secondary school students	Mixed-method (explanatory sequential) design; quasi-experimental and individual students' interviews; n = 208	The interviewed students perceived CTCA as a significant contributor to their learning achievement through positive learning experiences. The majority of the students reported that the approach promotes their active engagement in mathematics classroom and significantly reduces their anxiety towards learning mathematics
Study 19 Reducing Underachievement and Promoting Critical Thinking Skills in Computer Studies Through a Culturally Sensitive Instructional Method.	To reduce underachievement in learning ICT concepts and enhance critical thinking skills of students using CTCA and Gbeleyi 1.0	Survey of difficult concepts in computer studies; explanatory sequential design; pre-test, post-test non-equivalent group design; interviews; n = 213	Some of the students reported that the use of cultural examples made the concepts easier for them to understand and the lesson was very interesting

Overall, the studies reported the substantial impact of CTCA in promoting positive attitudes towards learning through increased learning engagement, motivation, and counter-

ing negative feelings towards learning such as anxiety. For example, following appropriate methodological procedures, study 15 reported the statistical evidence [F(1, 204) = 16.66; $p = 0.00$] of the effectiveness of CTCA in reducing mathematics anxiety. Corroborating this with qualitative findings, the interviewed students reported that the contextual examples used to explain the concepts of set and the use of humor during every lesson made the mathematics lessons enjoyable; hence, they felt less anxious and more interested in engaging with mathematics lessons. The findings indicated that the integration of CTCA into teaching abstract mathematics concepts helps students become familiar with the concepts, thereby promoting their interest in learning while feeling less anxious during mathematics lessons.

5. Discussion

With the commitment to accommodate and encourage marginalized students to learn, love, and live science, CTCA emerges as a pedagogical approach to breaking the barriers to meaningful learning of STEM concepts. This review was conducted to provide insight into how CTCA has been used and its impact on students' outcomes. Though CTCA is a relatively new teaching approach, valuable information can be obtained on its current adoption in STEM education, possible guidelines and directions for its continuous implementation in STEM classrooms, and implications for future research. In organizing these insights, we address each of our review questions in turn while we draw on evidence from the synthesized studies.

5.1. Concepts in Mathematics, ICT, and Sciences Treated with CTCA

Our first review objective was to find out the difficult concepts that have been covered using the culturo-techno-contextual approach in pursuance of the goal to break the barriers to meaningful learning of STEM concepts. Our findings revealed a more significant implementation of CTCA in science than other STEM content areas. The review has shown that in biology, variation and evolution have received considerable attention in making the concept easy to learn and understand. The repeated exploration of these concepts could be explained by the fact that they ranked as the most difficult concepts in biology [17]. Other difficult concepts, including genetics, which ranked the second most difficult concept, ecology, cell division, tissue, and supporting system and nutrition have also been treated to ensure meaningful learning of biology concepts.

Apart from the perceived difficulty associated with these concepts, research has shown that the contents of these topics account for a large proportion of questions in the standardized West Africa Senior Secondary Certificate Examinations (WASSCE) with reports of persistent poor performance [28,29]. This explanation justifies the treatment of the concepts of ecology and cell division as they were not included in the ranking of the twenty difficult concepts in biology [17]. In line with other studies on difficult concepts [30,31], these concepts are challenging to teach and understand. For chemistry concepts, significant contributions are noted in nuclear chemistry and electrochemistry. These concepts ranked the first and the eleventh concepts perceived as most difficult in chemistry. The difficult nature of physics concepts often makes it challenging to find competent teachers with high pedagogical content knowledge in the field [32,33], reflected in the limited research conducted in the field with regard to using CTCA. This underscores the fact that teachers' broad knowledge and deep understanding of the contents play a key role in the successful implementation of CTCA in STEM classrooms.

The underperformance of students in physics has been demonstrated to be caused by the way teachers deliver the content to students in the face of perceived difficulty in learning and understanding the concept [34,35]. Other teaching methods have been used extensively to improve students' performance in physics. Many studies utilized jigsaw

methods, think–pair–share, and flipped classroom methods. One of the significant obstacles regarding integrating CTCA into learning has been the critical thinking required to find STEM-related cultural knowledge [16]. The restricted number of studies in physics and mathematics indicates how less easy it is to find meaningful connections between STEM concepts and cultural knowledge, beliefs, or practices. This is in tandem with the criticism regarding the lack of applicability of culturally relevant teaching to mathematics and other mathematical-based subjects [11]. However, the research reports on implementing CTCA on refractive indices in physics and set theory in mathematics (see study 14 and 15) have set the stage, providing relevant and helpful insights in understanding applicability and making the connections evident.

Difficult concepts in ICT have received tremendous attention from different researchers. These range from the most difficult concept, flowcharting, the second most difficult, algorithms, the fourth, program development cycle, the fifth, machine language to the seventh and ninth, which are logic circuit and networking, respectively. The difficulties associated with these concepts were attributed to inappropriate pedagogical methods of teaching the concepts and the lack of access to computers for hands-on activities in view of the abstract nature of the concepts. Additionally, students reported that their teachers provide few explanations, using big vocabularies to explain the concepts [17,36]. All of these create barriers to meaningful learning of ICT concepts. In breaking these barriers, CTCA allows access to internet-enabled devices which gives students the opportunity to practice what they have learned in class. The related cultural knowledge and contextual examples provide concrete representation of the concepts, making them less abstract and easy to understand. This aligns with the position of ref. [37], which argued that the teaching and learning of technology is effective when they are more culturally responsive.

5.2. Culturo-Techno-Contextual Approach and Students' Outcomes

The need to improve the academic achievement of African students in STEM education using contextually and culturally relevant methods is evident. The reports of the underperformance of students in science in many African countries are persistent due to the continuous use of methods of teaching that are not context-specific [16,17]. In our review synthesis, CTCA was repeatedly demonstrated to have positive impacts on students' academic achievement. This finding is corroborated by previous reviews on the use of culturally relevant pedagogy [9,11]. However, focusing only on test scores for determining "achievement" might be misleading as there are other important measures of learning that significantly demonstrate the actual impact or life-long learning effects of a teaching approach. Learning is not just a cognitive function, but also a function of behavioral change and skills development which were categorized into effective (for example, motivation, interest, feelings, engagement, and attitudes towards learning) and psychomotor (for example, coordination, precision, articulation, and perception) domains [38]. This brings us to the first limitation of the reviewed studies: lack of robust qualitative empirical studies that would provide insights into the ways in which CTCA might support STEM teaching and learning as well as identifying which aspects of CTCA significantly contribute to positive teaching and learning experience.

Instead, the majority of the studies reviewed have used quantitative methods that lack depth and attention to behavioral change. Moreover, students' and teachers' experiences have not been examined thoroughly. While few studies used a mixed-method approach, where little additional qualitative data were collected, often from a very short period and/or limited sample size to examine students' perception, no study has investigated teachers' perceptions regarding the ease of implementing the approach. This finding is in contrast with the findings of the previous systematic review on the use of culturally

responsive pedagogy in computing [39], which found the main outcome measures in all 12 studies reviewed to be related to students' attitudes towards computing.

In agreement with ref. [9], it would be beneficial to move beyond the validity of test scores as predictors of academic achievement. For future research, we recommend that increased focus in affective domains should be considered as they represent real gains in academic knowledge, skills acquisition, and life-long learning. By implication, the connection of CTCA to positive student outcomes requires an expansion of "achievement" beyond only test scores to include other qualitative measures of academic knowledge and skills.

With regard to skills development, the potency of CTCA has been examined on critical thinking skills. While this is considered a unique contribution of CTCA to promoting quality education by addressing 21st-century skills, methodological issues relating to how critical thinking was taught and measured raise concerns that question the findings of the studies in this category. Particularly, the review of the methods of teaching and measuring critical thinking skills in a biology concept reported by study 8 reveals some inappropriateness. The reported learning activities were not tailored to critical thinking activities and the construct of critical thinking tests items was not valid. The Nutrition Critical Thinking Test (NCTT) was noted to be a multiple-choice test that contains questions on biology content which is often used to assess students' understanding of the learning objectives. Such test items have less potency in determining substantial change in students' critical thinking skills as the measure of critical thinking skills goes beyond conceptual knowledge to include the ability to efficiently apply the knowledge to solve real-life problems [40]. Nonetheless, no negative or lower impacts on critical thinking skills compared to the other teaching methods were reported.

The analysis in this study also provides valuable insights into how teachers or researchers implemented CTCA to promote meaningful learning of students. These will help to educate teachers and STEM educators about what culturally relevant pedagogy means and looks like in STEM classrooms. In the reviewed studies, the implementation of CTCA followed the five-step process featuring pre-lesson assignments, group activities, contextual referents, cultural reflection, and lesson summary. In reference to culturally relevant theory on which CTCA rests, the application of CTCA in the classroom has often displayed the tenets of culturally relevant education which propose the "production of students who can achieve academically, demonstrate cultural competence, and develop students who can both understand and critique the existing social order" [4] (p. 474). In producing students who can achieve academically, the reviewed studies reported how the approach helped the students to perform better than their control counterparts. Also, in general, the students scored higher than their pre-intervention tests. The qualitative findings revealed a variety of ways through which the approach enabled the students to indeed achieve. The students reported how the cultural and contextual referents concretized their understanding of the STEM concepts. Narration from a student reads as follows:

"The aspect of the teaching that aided my understanding the most was when the teacher used some of the things that we do in our homes to explain the concepts. The set of "agbada" attire that was used to exemplify the concept of set, made the concept very clear. It is so exciting to discover that many of our day-to-day activities have connections with mathematics concepts. I could never have imagined" {study 15} (p. 11).

The research also reported the lesson summary as a valuable contributor to students' academic achievement. Most of the participants reported that the lesson summaries enhanced their learning engagement, with many of their interview responses reflecting expressions like "I became interested in learning", and "I enjoyed attending classes". The lesson summaries can be viewed as the deliberate act of the teacher to help the students re-

member what they learned during the course of every lesson. This reflected the exemplary practice of culturally relevant pedagogues [4], helping their students to be academically successful through the implementation of "what works".

Besides encouraging students to achieve, teachers must also help students maintain their cultural integrity while succeeding academically. In promoting cultural competence, the reviewed studies reported how students in all the content areas likened cultural knowledge or practice in their culture to the concepts and gained pride in their culture. In science classrooms, students began to appreciate the relevance of their culture to learning, finding value in knowledge creation through varieties of their related cultural knowledge. Meanwhile, in mathematics, it was reported that the students gained cognitive abilities to solve problems.

The research attributed this success to the cultural aspect of CTCA which entails the engagement of parents, families, and communities in the learning process and bringing students' day-to-day life experiences into the classroom. The challenge of implementing culturally relevant teaching in the classroom lies in recognizing and acknowledging the ethnically diverse culture of students. Hence, in a CTCA class, alongside parents' and students' submissions, teachers also bring their own perspectives of STEM-relevant cultural knowledge and life experiences into the classroom.

For example, one of the studies reported using contextual examples of common cultural practices among the three major ethnic groups in Nigeria (Hausa, Igbo, and Yoruba) such as their cultural festivals, traditional attires, and recipes to explain the concepts of variation in biology. Because the students were indeed encouraged to bring their diverse cultural perspectives into the classroom, they were able to develop cultural competence as they learned to value their own and others' cultural perspectives.

6. Conclusions and Implications for Practice and Future Research

This systematic review provided an overarching discussion of the impacts of CTCA in breaking the barriers to meaningful learning of STEM concepts. It is clear that CTCA has repeatedly been effective in helping students understand difficult STEM concepts and improving their academic achievement. This synthesis holds important implications for future research on CTCA in STEM teaching and learning both for theory and practice. These implications also point to the possible integration of culturally and contextually sensitive teaching strategies into African classrooms, informing the best practices for teaching STEM concepts in the African context.

6.1. Requirements for Sustainable Implementation of CTCA

Based on the findings of the reviewed studies, we concluded that implementing CTCA in secondary schools requires several interventions at the policy level and active support from STEM educators. For policy makers, we recommend the development of curriculum guidelines that include local STEM applications, such as using indigenous engineering practices to teach physics. This will aid the flexibility of integrating cultural examples into STEM teaching by the teachers, while aligning with global education standards. However, to effectively implement CTCA, teachers (pre-service and in-service) need to be trained in digital literacy, contextualized teaching methods, and culturally relevant pedagogy. Hence, we also recommend the organization of CTCA-focused workshops where teachers learn how to integrate community knowledge, technology, and real-world problems into their lessons. While one of the limitations of implementing CTCA was reported to be limited knowledge of STEM-related cultural practices among the students and teachers, we recommended that policy makers, in collaboration with STEM educators, should create localized e-learning platforms that include case studies from African agriculture, local

climate science, or indigenous mathematical methods which can be used as cultural and contextual referents during CTCA-powered lessons.

Also, ensuring the long-term success of the culturo-techno-contextual approach (CTCA) in low-resource settings requires strategic planning, cost-effective implementation, and strong community engagement. Some challenges to implementing CTCA in resource-constrained environments are limited access to digital tools and internet accompanied by insufficient funding to procure digital infrastructure and lack of professional development for teachers. All of these contribute to teachers' resistance to changing their traditional teaching methods. However, to ensure the adoption and long-term impact of CTCA in these educational settings, we recommend leveraging existing community ICT centers through partnership to give students access to digital tools, encouraging teacher mentorship programs where experienced CTCA educators coach newcomers on best practices for implementing CTCA. There is also the need to incentivize teacher retention, where the adoption and effective implementation of CTCA is accompanied by recognition and rewards through grants, awards, or professional development opportunities. For researchers, this study provides a guide to carrying out sustainable and replicable studies in the field of science, technology, and mathematics.

6.2. Examining Students' and Teachers' Experiences Through Explorative Qualitative Studies

Our systematic review further indicated that all studies used quantitative approaches (using achievement tests for objective measures of learning gains) to evaluate the effects of CTCA on students' success. Studies that utilized qualitative analysis revealed more about students' learning experience and how the approach contributed to their understanding and academic achievement, with themes such as increased classroom engagement, improved knowledge retention, and motivation to learning emerging as central to students' improvement in STEM achievement. Missing in the literature are more explorative qualitative studies on students' and teachers' experiences with implementing CTCA in the classroom, in order to gain a better understanding of how CTCA might support science engagement and learning.

CTCA was designed to tackle the barriers impeding meaningful understanding of STEM concepts. Barriers such as the commonly held view among students that science is difficult to learn, the cognitive unreadiness of African students to process the formal operational concepts in science, the low motivation level of many African students to learn, and particularly, the perceived abstractness of science concepts which is rooted in the great distance between science discourse and everyday discourse or between the language of science and the mother tongue came tumbling down with CTCA. These factors are clearly embedded in the affective characteristics of the students. Thus, beyond cognitive assessment, we recommend more qualitative studies to further evaluate attitudinal or behavioral changes using rich and detailed data (not only test scores) to explain how and why students demonstrated changes in attitude with CTCA. Classroom observation will also be a helpful tool in shedding light on how the approach informs changes in the affective domains of students' learning.

6.3. Engaging in Longitudinal Studies

This review reveals varying intervention periods, ranging from three weeks to six weeks, with 80 min of lessons per week. These periods are considered short in view of study objectives like reducing students' anxiety, promoting feelings of STEM identity, and seeing significant changes in students' attitude towards learning. Several studies on the use of culturally sensitive approaches have shown that positive changes in these measures tended to be more evident for longer interventions [39,41–43]. Moreover, only a few students

within the same educational district and state were typically being served or evaluated in each study. As such, the generalization of findings in these studies requires great caution. To improve the validity of the findings of these studies, future research is required with long-term intervention (including longitudinal studies), using larger and more diverse samples to investigate the long-term benefits and effect of CTCA on students' affective domains such as attitudes, interests, motivation, and feelings towards STEM learning.

6.4. Comparing the Effectiveness of CTCA with Other Innovative Approaches

While there are other teaching methods that are consciously used by teachers to teach STEM concepts in our classrooms, the research on use of CTCA has mainly compared CTCA with the traditional lecture method. Although CTCA combines the strength of other effective teaching methods such as collaboration, discussions, classroom interactions, flipped classroom and technology-aided instructions, it would be helpful to evaluate the effectiveness of CTCA in comparison with any of these approaches. This will provide insights into where the strengths and weaknesses of CTCA lies, thereby helping the teachers to understand what works for their students and appropriately navigate and maximize the strengths of the approach in teaching and learning process.

6.5. The Scalability of CTCA Beyond Africa

The culturo-techno-contextual approach is designed to integrate cultural, technological, and contextual elements into education, making learning more meaningful and relevant. While findings from this review have shown that CTCA has been primarily explored in African settings, its scalability beyond Africa is evident in its core principle: cultural adaptability. All societies have unique traditions, values, and ways of knowing; this can be leveraged upon for meaningful learning of STEM concepts. However, in multicultural and highly diverse societies (e.g., the U.S. and Europe), designing a culturally inclusive curriculum that accommodates multiple perspectives may require additional customization such as the integration of culturally relevant storytelling, case studies, and indigenous knowledge specific to their region. Moreover, CTCA emphasizes technology integration, which aligns well with global trends in digital education. Also, CTCA aligns well with constructivist and student-centered learning, which is widely promoted in global education. Although some countries still rely heavily on standardized curricula and rigid assessment systems, limiting the flexibility needed for CTCA to thrive, integrating CTCA in project-based learning or alternative assessments could ease the transition. Hence, given its unique configuration, CTCA has strong potential for scalability beyond Africa, but success depends on context-specific adaptations. Countries focusing on context-based, inclusive education (such as parts of Asia, Latin America, and Indigenous communities in North America) could particularly benefit from its application.

6.6. Other Implications

While we acknowledge the need for the expansion of CTCA in all areas and levels of education, developing teachers' knowledge and confidence in the use of CTCA is paramount to the successful implementation of the approach. If our goal is to ensure students at all educational levels learn meaningfully, then we need to invest in quality teachers equipped with necessary tools to teach meaningfully and prepared to promote students' success.

With the nascency of CTCA, research exploring its effectiveness in STEM is still emerging. Our selection criteria of reviewing only peer-reviewed journals and conference papers may have accounted for the relatively limited number of studies included in this review. By implication, we may have excluded some studies that demonstrated richer applications of CTCA in STEM education because they were reported as PhD or master's

dissertations, undergraduate projects, books, or non-peer-reviewed conference papers. This clearly suggests that this review does not represent an exhaustive demonstration of the effectiveness of CTCA in promoting meaningful learning of difficult STEM concepts. Regardless, given that CTCA is committed to ensuring the rewriting of the narratives about the African scientific knowledge, this review is significant and will serve those willing to participate in the efforts by providing evidence-based research that brings the African knowledge system to the frontier of teaching and learning.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su17052310/s1, PRISMA Checklist.

Funding: The APC for this study was funded by the Africa Centre of Excellence for Innovative and Transformative STEM Education, Lagos State University, Ojo (LASU-ACEITSE).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Baeten, M.; Struyven, K.; Dochy, F. Student-centred teaching methods: Can they optimise students' approaches to learning in professional higher education? *Stud. Educ. Eval.* **2013**, *39*, 14–22. [CrossRef]
2. Gezim, B.A.R.A.; Xhomara, N. The effect of student-centered teaching and problem-based learning on academic achievement in science. *J. Turk. Sci. Educ.* **2020**, *17*, 180–199.
3. Precious, E.C.; Feyisetan, A.V.A. Influence of teacher-centered and student-centered teaching methods on the academic achievement of post-basic students in biology in Delta State, Nigeria. *Teach. Educ. Curric. Stud.* **2020**, *5*, 120–124. [CrossRef]
4. Ladson-Billings, G. Toward a theory of culturally relevant pedagogy. *Am. Educ. Res. J.* **1995**, *32*, 465–491. [CrossRef]
5. Gay, G. *Culturally Responsive Teaching: Theory, Research, and Practice*, 2nd ed.; Teachers College Press: New York, NY, USA, 2010.
6. Au, K.H.; Kawakami, A.J. Cultural congruence in instruction. In *Teaching Diverse Populations: Formulating a Knowledge Base*; SUNY Press: Albany, NY, USA, 1994; Volume 24.
7. Johnson, C.C. The road to culturally relevant science: Exploring how teachers navigate change in pedagogy. *J. Res. Sci. Teach.* **2011**, *48*, 170–198. [CrossRef]
8. Grimberg, B.I.; Gummer, E. Teaching science from cultural points of intersection. *J. Res. Sci. Teach.* **2013**, *50*, 12–32. [CrossRef]
9. Aronson, B.; Laughter, J. The theory and practice of culturally relevant education: A synthesis of research across content areas. *Rev. Educ. Res.* **2016**, *86*, 163–206. [CrossRef]
10. Brown, J.C. A metasynthesis of the complementarity of culturally responsive and inquiry-based science education in K-12 settings: Implications for advancing equitable science teaching and learning. *J. Res. Sci. Teach.* **2017**, *54*, 1143–1173. [CrossRef]
11. Abdulrahim, N.A.; Orosco, M.J. Culturally responsive mathematics teaching: A research synthesis. *Urban Rev.* **2020**, *52*, 1–25. [CrossRef]
12. Hernandez, A. Closing the achievement gap in the classroom through culturally relevant pedagogy. *J. Educ. Learn.* **2022**, *11*, 1–21. [CrossRef]
13. Okebukola, P.A.; Ige, K.; Oyeyemi, A.; Olusesi, O.; Owolabi, O.; Okebukola, F.; Osun, G. Exploring the impact of culturo-tecno-contextual-approach (CTCA) in tackling underachievement in difficult concepts in biology. In Proceedings of the National Association for Research in Science Teaching (NARST) Annual Conference, Baltimore, MD, USA, 14–17 April 2016.
14. Abolaji, T.; Owolabi, T.; Lameed, S.N.; Ogundowole, A.; Ige, A.M.; Mustapha, A.G. Teaching Conservation of Natural Resources with Culturally Responsive and Context Specific Environment: The Stance of Cultro-Techno-Contextual Approach. *J. Educ. Sci.* **2025**, *9*, 26–42. [CrossRef]
15. Gbeleyi, O.A.; Olusegun, O.P.; Tetteh, A. Reducing Underachievement and Promoting Critical Thinking Skills in Computer Studies Through a Culturally Sensitive Instructional Method. *Res. Educ. Learn. Innov. Arch.* **2023**, 81–98. [CrossRef]
16. Oladejo, A.I.; Olateju, T.T.; Okebukola, P.A.; Braimoh, D.S. I am Black and I am a girl-child, can I still be a scientist? *Sch. Sci. Math.* **2024**, 1–19. [CrossRef]
17. Okebukola, P.A. *Breaking Barriers to Learning: The Culture-Techno-Contextual Approach (CTCA)*; Sterling Publishers: Delhi, India, 2020.
18. Moses, A. *Culture, Contexts and Learning*; Marshall Press: New York, NY, USA, 1992.
19. Heidegger, M. The question concerning technology. *Read. Philos. Technol.* **1977**, 9–24.

20. Mensah, F.M. Culturally relevant and culturally responsive. *Sci. Child.* **2021**, *58*, 10–13. [CrossRef]
21. Gbamanja, S.P.T. Nexus Between Science and Culture: A Panoramic View from Sierra Leone. *J. Afr. Cult. Int. Underst.* **2014**, *3*, 16–24.
22. Atwater, M.M. Social constructivism: Infusion into the multicultural science education research agenda. *J. Res. Sci. Teach. Off. J. Natl. Assoc. Res. Sci. Teach.* **1996**, *33*, 821–837. [CrossRef]
23. Vygotsky, L.S. *Mind in Society. The Development of Higher Psychological Processes*; Harvard University Press: Cambridge, MA, USA, 1978.
24. Ausubel, D.P. A subsumption theory of meaningful verbal learning and retention. *J. Gen. Psychol.* **1962**, *66*, 213–224. [CrossRef]
25. Gay, G. *Culturally Responsive Teaching: Theory, Research, and Practice*, 3rd ed.; Teachers College Press: New York, NY, USA, 2018.
26. Page, M.J.; Moher, D.; Bossuyt, P.M.; Boutron, I.; Hoffmann, T.C.; Mulrow, C.D.; Shamseer, L.; Tetzlaff, J.M.; Akl, E.A.; Brennan, S.E.; et al. PRISMA 2020 explanation and elaboration: Updated guidance and exemplars for reporting systematic reviews. *Bmj* **2021**, *372*. [CrossRef]
27. Tawfik, G.M.; Dila, K.A.S.; Mohamed, M.Y.F.; Tam, D.N.H.; Kien, N.D.; Ahmed, A.M.; Huy, N.T. A step by step guide for conducting a systematic review and meta-analysis with simulation data. *Trop. Med. Health* **2019**, *47*, 46. [CrossRef]
28. Etobro, A.B.; Fabinu, O.E. Students' perceptions of difficult concepts in Biology in senior secondary schools in Lagos State. *Glob. J. Educ. Res.* **2017**, *16*, 139–147. [CrossRef]
29. Akinbadewa, B.O.; Sofowora, O.A. The effectiveness of multimedia instructional learning packages in enhancing secondary school students' attitudes toward Biology. *Int. J. Stud. Educ.* **2020**, *2*, 119–133. [CrossRef]
30. Lopez, E.N.B.; Maraño, C.M.B.; Origenes, R.W.; Pizaña, A.D.; Salmo, J.M.; Picardal, J.P. Content Analysis of Cell Division Concepts in Senior High School Biology Textbooks. *J. Biol. Educ. Indones. (J. Pendidik. Biol. Indones.)* **2022**, *8*, 159–177. [CrossRef]
31. Gungor, S.N.; Ozkan, M. Evaluation of the concepts and subjects in biology perceived to be difficult to learn and teach by the pre-service teachers registered in the pedagogical formation program. *Eur. J. Educ. Res.* **2017**, *6*, 495–508. [CrossRef]
32. Keller, M.M.; Neumann, K.; Fischer, H.E. The impact of physics teachers' pedagogical content knowledge and motivation on students' achievement and interest. *J. Res. Sci. Teach.* **2017**, *54*, 586–614. [CrossRef]
33. Coffie, I.S.; Frempong, B.B.; Appiah, E. Teaching and learning physics in senior high schools in Ghana: The challenges and the way forward. *Adv. Res.* **2020**, *21*, 35–42. [CrossRef]
34. Obafemi, D.T.; Onwioduokit, F.A. Identification of difficult concepts in senior secondary school two (SS2) physics curriculum in Rivers state, Nigeria. *Asian J. Educ. E-Learn.* **2013**, *1*, 317–322.
35. Bello, T.O.; Opaleye, O.S.; Olatunde, A.N. Perceived difficult concepts in physics among senior secondary school students in Ife central local government area of Osun state. *Int. J. Contemp. Issues Educ.* **2018**, *3*, 30–41.
36. Agbanimu, D.O.; Okebukola, P.A.; Onowugbeda, F.U.; Peter, E.O.; Oladejo, A.I.; Gbeleyi, O.A.; Ademola, I.A. Mitigating difficulty in Computer studies through Culturo-Techno-Contextual Approach. *J. Educ. Res.* **2025**, *118*, 1–9. [CrossRef]
37. Scott, K.A.; Sheridan, K.M.; Clark, K. Culturally responsive computing: A theory revisited. *Learn. Media Technol.* **2015**, *40*, 412–436. [CrossRef]
38. Bloom, B.S.; Engelhart, M.D.; Furst, E.J.; Hill, W.H.; Krathwohl, D.R. Taxonomy of educational objectives: The classification of educational goals. In *Handbook 1: Cognitive Domain*; David McKay: New York, NY, USA, 1956.
39. Leonard, H.C.; Sentance, S. Culturally relevant and responsive pedagogy in computing: A Quick Scoping Review. *Int. J. Comput. Sci. Educ. Sch.* **2021**, *5*, 3–13. [CrossRef]
40. McPeck, J.E.; Scriven, M. *Teaching Critical Thinking: Dialogue and Dialectic*; Routledge: London, UK, 2016. [CrossRef]
41. Ryoo, J.J. Pedagogy that supports computer science for all. *ACM Trans. Comput. Educ. (TOCE)* **2019**, *19*, 1–23. [CrossRef]
42. Yang, W.; Peh, J.; Ng, S.C. Early childhood teacher research and social-emotional learning: Implications for the development of culturally sensitive curriculum in Singapore. *Policy Futures Educ.* **2021**, *19*, 197–215. [CrossRef]
43. Oladejo, A.I.; Olateju, T.T.; Ahove, M.A.; Suwadu, B. A Beautiful Garment from Old Fabrics: The Analogy of Culturo-Techno-Contextual Approach for Meaningful Learning in Science. *Res. Sci. Technol. Educ.* **2024**, 1–24. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.