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# Mathematics for sustainable development implementation at secondary school level: A scoping review

Ismael Gaanya [1]*, Marjorie Sarah Kabuye Batiibwe [1], Bettina Dahl [2], John Magero Mango [1], Godfrey Mayende [1]

[1] Makerere University, UGANDA
[2] University of Bergen, NORWAY
***Corresponding Author:** gaanya@gmail.com

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**ABSTRACT**

Mathematics for sustainable development (MSD) is an intervention to strengthen the teaching of mathematics using the cross-cutting issues reflected in Uganda's secondary mathematics curriculum. MSD aims to develop values, skills, attitudes, and knowledge using the three educations for sustainable development (ESD) domains-environment, social, and economic to achieve the 17 global sustainable development goals (SDGs). It is significant to understand the MSD phenomenon and its related attributes for it to be successfully implemented. However, there is a paucity of literature on MSD pedagogies at the secondary school level in Africa. This scoping review aims to offer concrete examples and approaches that enhance the successful implementation of MSD from reviewed articles published about the lower secondary level from 2005 to 2022. The findings identified four key aspects that promote MSD learning, i.e. MSD-based curriculum reforms, CPD for in-service teachers, interdisciplinary teaching, and assessment.

**Keywords:** education for sustainable development, mathematics for sustainable development, secondary school, sustainable competencies, scoping review

## INTRODUCTION

The implementation of Mathematics for Sustainable Development (MSD) in developing countries like Uganda is still challenging. The Ugandan lower secondary curriculum promotes mathematics teaching for sustainability through cross-cutting issues such as poverty, corruption, environment, and HIV that link in to the 17 SDGs.

Uganda's secondary mathematics teachers' practices are associated with poor teaching approaches dominated by formulaic theoretical talk-and-chalk but partially practical activities that do not fully enhance students' engagement (Hiraoka & Nicholas, 2013), and limited content knowledge, exploration and investigation of problems relating to real-life contexts (Batiibwe, 2019; Namukasa et al., 2010; Opolot-Okurut et al., 2008). These challenges led to the introduction of the Secondary Science and Mathematics (SESEMAT) in-service training program in Uganda (Komakech & Osuu, 2014). This program focuses on building competencies in Activity Learner-centred Encouragement and Improvement (ALEI) and Planning Improvement Evaluation and Improvement (PIEI) (Kariisa et al., 2015).

Another practical way of teaching MSD is the transformation approach, where learners are made to investigate quantities of items such as sugar in various beverages, represent the data on a pictograph, and determine the drink they prefer to live a healthy life (Kim & Pang, 2022). The task enhances the development of sustainable skills in the learners, such as a preference for healthy beverages, while gaining a deeper understanding of the content being taught.

Ningsih and Juandi (2019) and Widiati and Juandi (2019) emphasize the importance of teachers possessing and applying the underlying knowledge and skills of ESD in mathematics to promote 21st-century skills. Renert (2011) identified two pedagogical approaches for MSD teaching: Sterling's model of educational responses to sustainability (accommodation, reformation, and transformation) and Edwards's mode of approaches to sustainability through seven stages (substance, avoidance, compliance, efficiency, commitment, local sustaining, and global sustaining).

The Government of Uganda's (2019) National Teacher Policy (NTP) advocates for the 6Cs: Curiosity, critical thinking, creativity, confidence, collaboration, and communication. These skills are crucial for students in developing effective and efficient human capital for sustainable learning. This is

aligned with Uganda's Vision 2040, which focuses on addressing Uganda's challenges of inadequate skills amongst the educated human resources (Balyejjusa, 2015). This is further reechoed by the National Planning Authority (2020), which laments that Uganda's human capital lacks the knowledge, skills, and attitudes necessary for building a foundation for achieving this vision.

Scoping reviews in the education field inform policy and practice and help map the nature of research on a concept such as MSD that needs to be explored (Arksey & O'Malley, 2005). Hence this review is justified by the fact that there is need for more research about sustainable pedagogiesfor science teaching at secondary school level in Africa (Barrett, 2017; Blatti et al., 2019) and Uganda in particular.

### Conceptual Understanding of Mathematics for Sustainable Development

MSD refers to the teaching of mathematics that makes use of the SDGs, SD, or ESD domains in addition to promoting the acquisition of 21st-century skills (communication, collaboration, critical thinking, and creativity (Serow, 2015). MSD teaching seeks to change learners in feelings, attitudes, values, and practices (Sterling & Orr, 2001). Therefore, operationalising sustainable competencies is highly advocated for in real classroom contexts (Cebrián & Junyent, 2015).

Hence, MSD teaching calls for the integration of sustainable development content during curriculum reforms followed by its accurate interpretation and application by the teachers (Husamah et al., 2022; Ningsih & Juandi, 2019).

Domínguez-González and Delgado-Martín (2022) call for alignment of the didactic triangle of content, teachers and students in order to advance mathematics teaching for sustainable development. The teachers should adapt to innovative pedagogies, and the students should be assessed for the way they achieve the competencies such as communication speaking, listening, doing exercises or writing.

### Rationale for this Scoping Review

A scoping review is used when there is a need to identify relationships and causal interpretation in a body of literature on a research concept that is not comprehensively reviewed (Cruz et al., 2022; Peters et al., 2015). According to Arksey and O'Malley (2005), the reasons for conducting a scoping study include mapping the nature of the research concept and finding research gaps in the existing literature. Scoping reviews help to identify gaps, clarify concepts, provide a comprehensive overview of the evidence, inform policymakers, help practitioners plan and deliver effective interventions, and examine emerging unclear evidence. They allow researchers to acquire working definitions and conceptual boundaries of a new or emerging research area and gain an overview of the heterogeneous bodies of its existing literature (Munn et al., 2018).

The advantage of scoping reviews over systematic reviews is that systematic reviews focus on specific research questions, while scoping reviews are broader and can collect information from a wide range of sources (Mak & Thomas, 2022). The study, therefore, utilises the scoping review approach to understand the teaching of mathematics that incorporates SDGs at the secondary school level, which has not been comprehensively researched (Barrett, 2017; Barwell, 2018). Scoping reviews sometimes use meta-analysis in reporting results. Meta-analysis uses quantitative measures and effect size to show the relationship between studies by aggregating data (Manfredo et al., 1996; Shelby & Vaske, 2008). Meta-analysis was not used since the fourteen papers identified were too few, with only four quantitative studies.

### Research Questions

The current study, therefore, analyses the research published on MSD at the lower secondary level. The study researched the literature that aimed to answer the following questions:

**RQ1** What teaching conditions moderate effective implementation of mathematics for sustainable development at the lower secondary school level?

**RQ2** What strategies are used to develop students' competencies during mathematics for sustainable development lesson implementation?

This article is structured in four sections; in the methods section gives an overview of the method used for the identification of relevant studies from different databases, inclusion and exclusion criteria, charting and information sorting, and summary and reporting of results. This is followed by the results section, which presents the main findings, and the discussion section, which presents the analysis of the existing work on moderating factors and strategies for the implementation of mathematics for sustainable concepts and reflections. Lastly, the conclusion section presents limitations and proposals for further research.

## METHODS

The protocol was developed using Levac et al. (2010) scoping review methodological framework consisting of six stages: stage 1, identification of research questions; stage 2, identification of relevant studies using different databases; stage 3, inclusion and exclusion criteria; stage 4, charting and information sorting based on key issues and themes; stage 5 summary and reporting of results including the implication for policy and practice; and stage 6 (optional) consists of consultation with key stakeholders to inform and validate study findings. The first 5 stages have been utilised in this scoping review. Stage 6 was excluded from this study as we only aimed to learn what the existing research was.

After deciding on the research questions used in this review, the study proceeded through the four stages described below.

### Stage 2: Identification of Relevant Studies from Different Databases

The scoping review stages were performed until March 2022. In stage 2, the relevant studies were identified using keywords related to "Mathematics for sustainable development at the lower secondary level". Asterisk (*) was used on math (math*) to cater to other similar words such as maths, mathematics, mathematical, etc., and sustain (sustain*) to cater for sustainable and sustainability.

The different blocks in all three database searches (Eric, EBSCO host, and Scopus) used the OR/AND Boolean operators. Intervention keywords included STEM teaching, Science teaching, and Science education. The rationale for the above selection is that mathematics is part of the acronym in STEM and part of the Sciences (Physics, Mathematics, Chemistry, Biology, and Agriculture) in this context.

Among the three databases used, Scopus was the only database that was able to generate a retrievable search code: TITLE-ABS-KEY ( ( ( "Math* education" OR "STEM education" OR "Science education" OR "Math* teaching" OR "STEM teaching" OR "Science teaching" ) AND ( "sustainab* development" OR "sustainab* development education" OR "sustainab* development teaching" ) AND ( "Secondary" OR "Middle" OR "Junior high" OR "lower secondary" ) ) ) AND PUBYEAR > 2004 AND PUBYEAR < 2023 AND ( LIMIT-TO ( DOCTYPE, "ar" ) OR LIMIT-TO ( DOCTYPE, "cr" ) AND ( LIMIT-TO ( LANGUAGE, "English" ) ).

The databases were chosen as they each represent respectable and acknowledged places for research. ERIC (Education Resources Information Center) is a digital library sponsored by the United States Department of Education and consists of 1.5 million records. EBSCOhost, a privately-owned company, is a large collection of databases in a wide range of subjects, while Scopus is the largest database of peer-reviewed literature with more than 75 million records. Thus, all three are likely to hit relevant quality research.

### Stage 3: Inclusion and Exclusion Criteria

The articles were subjected to several eligibility and exclusion criteria. Regarding literature and document type, only journal articles and conference articles were included; journal articles are subjected to review and provide key outcomes of research on a particular topic. Books and Book chapters were excluded, for they are often not indexed in scholarly databases.

For easy understanding and to avoid language translation issues, the selection only filtered English articles. In addition, the articles selected were published between 2005 and 2022, making 17 years. The rationale for this timeline is as follows: The initial year of 2005 is based on the United Nations declaration of the (2005-2014) decade of ESD, which committed all UN member countries to focus on education as a means for sustainable development (Jegstad & Sinnes, 2015; UNESCO, 2006). The year 2022 is selected to see what has been done on the topic since 2005. Thus, all scholarly articles from 1 January 2005 to 31 December 2022 were selected. Articles that focused on SD and ESD at the lower secondary school level were included, excluding those at the primary, upper secondary level, and higher institutions of learning. This was because in 2020, the government of Uganda rolled out the integration of cross-cutting issues in Uganda's Competence-Based Curriculum (CBC) at the lower secondary school level, which supports SDGs integration in mathematics teaching. This program is yet to be introduced at the higher secondary school level (Wambiya & Ogula, 2023).

### Stage 4: Charting and Information Sorting about Key Issues and Themes

After combining all the eligible articles from the different databases: Eric (49), EBSCO HOST (90), Scopus (44), and 2 articles were obtained: Mathematics Teachers Facing the Challenges of Global Society: A Study in Primary and Secondary Education in Spain (Santamaría-Cárdaba et al., 2021), and Practical pedagogy for embedding ESD in science, technology, engineering, and mathematics curricula (Hopkinson & James, 2010) were obtained after checking references of the relevant review articles and 2 other articles from Google Scholar: Philosophy of mathematics education for sustainable development (Widiati & Juandi, 2019) and, Achievement of ESD through mathematics learning (Ningsih & Juandi, 2019) resulting in 4 articles from other sources.

The reasons for the four articles not captured by the three databases included:

(1) Absence of key terms in the article titles related to ESD and SD for instance, Santamaría-Cárdaba et al. (2021) article, used 'Global Society,' refer to **Table 1** and

(2) The remaining three articles have the key terms but possibly their publication journals are not indexed in the three databases the study used.

**Table 1.** Showing the 14 articles used in the review

| Title | Purpose |
|---|---|
| 1. Sustainable development research in Eurasia Journal of mathematics, Science and Technology Education: A systematic literature review (Husamah et al., 2022) | To review and compare investigations of research on the topic of sustainable development articles published by Eurasia Journal of Mathematics, Science, and Technology Education |
| 2. An analysis of Sustainable Activities in Japanese, Korean, and Singapore Elementary Mathematics Textbooks (Kim & Pang, 2022) | To explore how contents related to sustainable development were presented in Japanese, Korean, and Singaporean elementary mathematics textbooks |
| 3. Arousing Early Strategic Thinking about SDGs with Real Mathematics Problems (Domínguez-González & Delgado-Martín, 2022) | To contribute to the field of civic education through the design of original math problems combining math secondary education curriculum with the predicament of 2030 |
| 4. Teachers' Candidates Awareness of Sustainable Development (Aydin & Keles, 2021) | To determine the "sustainable Development' awareness of prospective teachers in five different branches of the Faculty of Education of a university department of Science Teaching, Primary School Teaching, Elementary Mathematics Teaching, Preschool Teaching, and Social sciences Teaching |
| 5. Mathematics for life: Sustainable mathematics education (Renert, 2011) | To examine the role that sustainability plays in education and mathematics education. |
| 6. STEM Education in Secondary Schools Teachers' Perspective Towards Sustainable Development (Nguyen et al., 2020) | To review how pedagogical approaches in science, technology, engineering, and mathematics (STEM) education can be deployed to teach concepts of sustainability |

**Table 1 (Continued).** Showing the 14 articles used in the review

| Title | Purpose |
|---|---|
| 7. Training in Mathematics Education from a Sustainability Perspective. A Case Study of University Teachers' Views (Moreno-Pino et al., 2022) | To explore the views of a group of university teachers from the area of Didactics of Mathematics in the Faculty of Education Sciences at Universidad de Cediz about Education for Sustainability and its integration in the field of training future teachers in mathematics education |
| 8. Construction of Mathematical Modelling for Teaching Evaluation Index System Based on the Delphi AHP Method (Zhang, 2022) | To establish an evaluation index system to accurately judge mathematics teachers' abilities based on the Delphi AHP method. |
| 9. Mathematic Education Meets Development Education: The Competency Mathematics Modelling combined with Global Skills and Competencies in a Secondary School Project in Germany (Schell-Straub, 2013) | To explore the role of mathematical tools in perceiving global key issues and threats such as poverty, climate change, conflicts, pandemics, and their interconnectedness. |
| 10. Promoting Sustainable Development in School Classrooms: Using Reciprocal Teaching in Mathematics Education (Aslam et al., 2021) | To explore the use of the reciprocal teaching instructional strategy for word-based mathematical problems at the elementary level. |
| 11. Mathematics Teachers' Facing the Challenges of Global Society: A Study in Primary and Secondary Education in Spain (Santamaría-Cárdaba et al., 2021) | To find out how teachers of mathematics with generalist training who teach in Primary Education (6-12) and teachers with more specific training who teach in Secondary Education and Baccalaureate (12-18) link SDGs within their subject. |
| 12. Achievement of ESD (Education for Sustainable Development) through mathematics learning (Ningsih & Juandi, 2019) | To examine the role that sustainability has played in education in general and in mathematics education in particular. |
| 13. Philosophy of mathematics education for sustainable development (Widiati & Juandi, 2019) | To examine the philosophy of ESD, especially in mathematics education. |
| 14. Practical pedagogy for embedding ESD in science, technology, engineering, and mathematics curricula (Hopkinson & James, 2010) | To highlight examples of embedded education for sustainability development within science and related curricula that are meaningful and relevant to teachers and students |

All the articles were combined in one Excel file, and 29 duplicates were removed from a total of 187 articles from all the databases. Next, was selection of the remaining 158 articles using abstracts and relevant titles related to the topic, of which a total of 113 articles were removed. These articles captured some of the ESD domains but were not about mathematics at lower secondary school teaching. They were about secondary school chemistry teaching, chemistry education, biology education, upper secondary students, and higher education. Articles such as "Effects of a training intervention to foster argumentation skills while processing conflicting scientific positions" and "Students' use of decision-making strategies with regard to socio scientific issues: An application of the Rasch partial credit model" did not include any of the keywords of interest. Subsequently, focus was put on 14 articles (see **Figure 1**) which were used for this analysis.

### Stage 5: Summary and Reporting of Results for Policy and Practice

In this scoping review, themes were constructed to present a narrative interpretation of the existing literature in the 14 selected papers. The review was confined to the identification of areas that promote MSD teaching in lower secondary, the current issues associated with teaching MSD, comparison across interventions about the concept, and the strengths and gaps of individual interventions. This, in turn, resulted in seven main themes: Five related to conditions that moderate the effective implementation of MSD at the lower secondary level and two related to the current classroom practices that develop students' competencies through its implementation. This revealed strong thematic overlaps between curriculum reform and teacher training; interdisciplinary teaching and curriculum reform and ESD domains; and interdisciplinary teaching and ESD domains, that fully enable conditions that moderate the effective implementation of mathematics for sustainable learning at the lower secondary level. In addition, the structure of student activities and ESD teaching approaches overlapped because the study also sought to identify students' competencies during the implementation of the MSD-based lesson.

## RESULTS

### Study Characteristics of the Selected Papers

The results of this scoping review are presented according to the trends associated with the selected articles about MSD with their characteristics, such as distribution by country, journals, number of articles by year, and methodology.

The "Mathematics for sustainable teaching" concept first appeared in 2011 in Renert's (2011) article "Mathematics for life: Sustainable mathematics education for life". By 2013, only two articles had been published, and there was a break for 5 years. **Figure 2** shows authors picking interest in the topic in 2011 and there is an increase in the papers from 2019. For instance, the search procedure yielded single articles from the years 2011 and 2013 and as many as 12 papers from 2019.

The trend of increase in the publication is due to international policy events. For instance, the United Nations (UN) dedicated the years 2005-2014 as the Decade of ESD (Jegstad & Sinnes, 2015; UNESCO, 2006), and in 2011 and 2013, there were 2 articles published in the field of integrating SDGs in Mathematics education at the secondary school level. In addition, the 12 articles in the last four years, between 2019 and 2022 inclusive, are attributed to UNESCO's 2030 Agenda framework that demands researchers to study and understand ESD (Shulla et al., 2020).

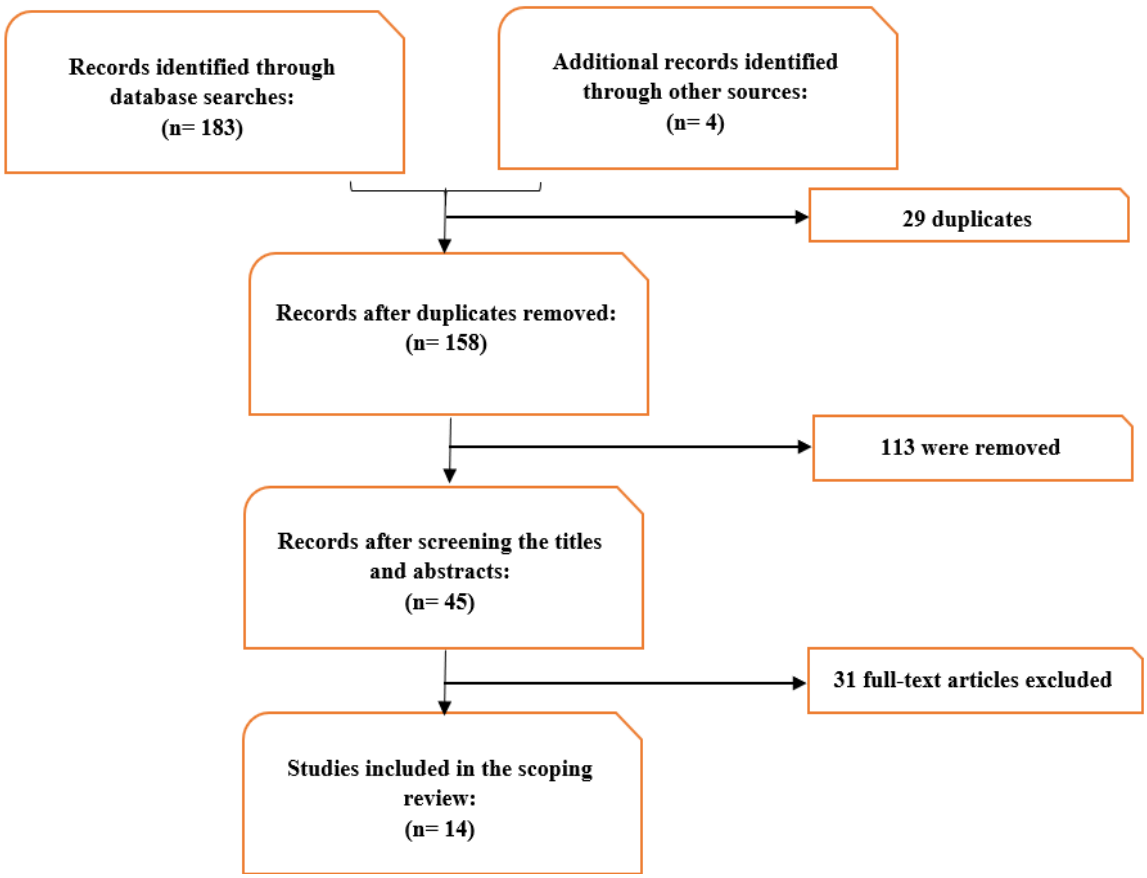


**Figure 1.** A scoping review flow chart process for articles retrieved in each stage (Source: Authors' own elaboration)

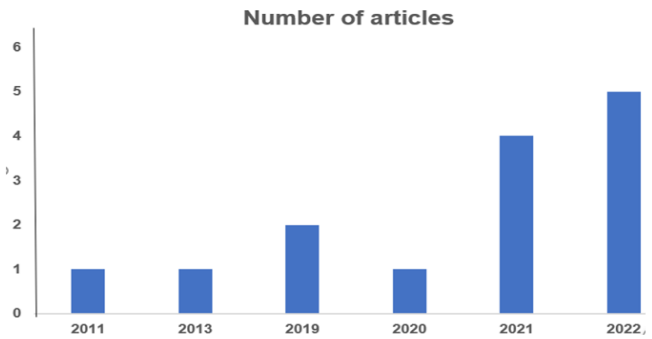


**Figure 2.** Number of selected articles according to year of publication (Source: Authors' own elaboration)

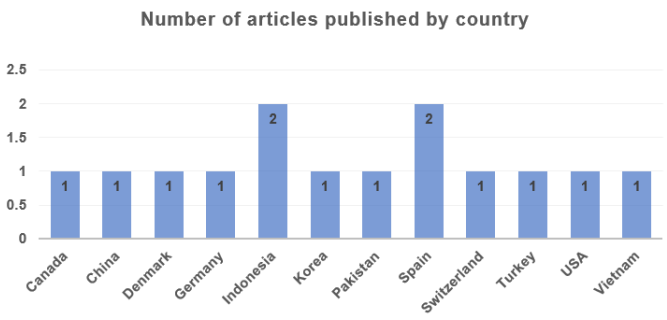


**Figure 3.** Number of articles published by country (Source: Authors' own elaboration)

Most of the articles were published in Europe and Asia, with Spain and Indonesia having more than other countries. **Figure 3** shows the distribution of the fourteen articles by country. The Asian contribution at the continental level is attributed to the Southeast Asian ESD measures in place, such as China and Korea, that have ESD inclusion guidelines and standards; Indonesia, Japan, Malaysia, and the Philippines integrate ESD into all subjects (Phang et al., 2016). Africa is absent in this area, even though it had more research about SDG3 of good health and well-being (Sweileh, 2020). This non-contribution by African countries is attributed to challenges such as varied and uncoordinated policy responses, the vast geopolitical, geospatial, and demographical realities, diverse cultures, languages, belief systems, and limited data sharing (Auriacombe & van der Walt, 2021).

The 14 articles in **Table 1** provide information about the title and their corresponding study purpose. The overview of how the 14 selected articles were cited is presented in **Figure 4**. It is observed that Renert's (2011) article "Mathematics for life: Sustainable mathematics education for learning" is the most cited article with 70 citations (while also being the oldest), followed by Nguyen et al.'s (2020) paper titled "STEM education in secondary schools teachers' perspective towards sustainable development".

Renert's article provides the Sterling model approaches to sustainability in mathematics education, categorising the different levels of mathematics activities in the textbooks as falling under accommodation (education about sustainability), reformation (education for sustainability), and transformation (education as sustainability). The paper further provides a mathematical ecological sustainability example that activates

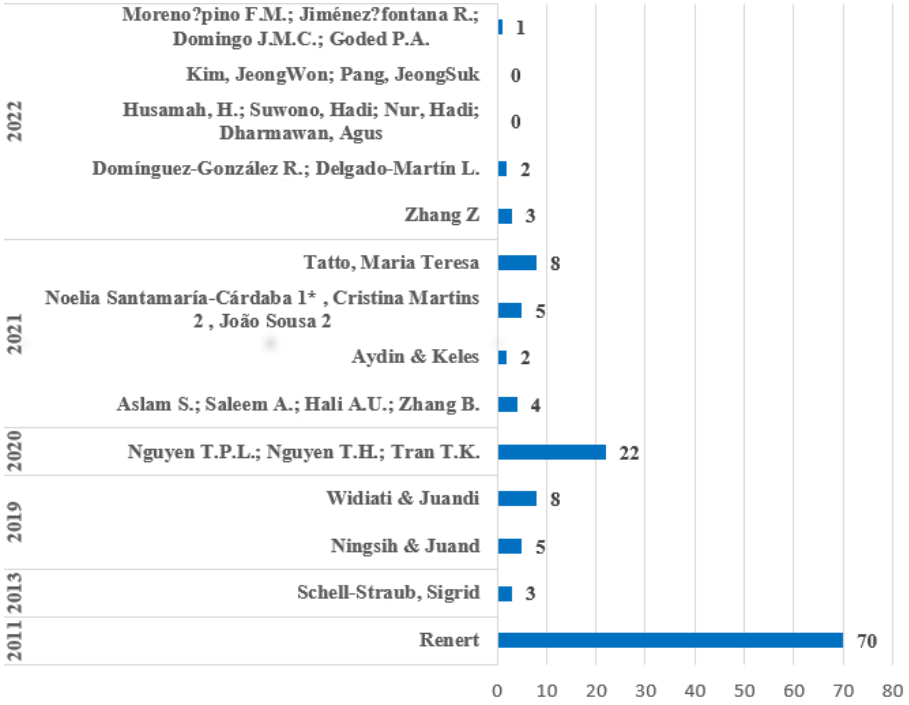


**Figure 4.** Citations of the selected articles (Source: Authors' own elaboration)

reasoning. The depletion of resources by eating cows as compared to eating chicken: For a kilogram of weight gain, a cow requires 7 kgs of grain, and a chicken requires 2 kgs of grain. This is three and a half times the resources needed for chicken. The implication of this article is to provide direction to curriculum and textbook developers in Uganda and Africa at large on designing MSD tasks using the Sterling model by aiming at the transformational level (highest level), which enhances change in the learners' attitude and behavior and develops feelings for others and the environment.

## Methological Approaches Used in the Selected Articles

8 out of the 14 articles were qualitative studies, 4 were quantitative, and 2 were mixed-methods studies. Most of the reviewed literature was non-experimental studies, which was a limitation of the study. Only one experimental study, titled Arousing early strategic thinking about SDGs with real mathematics problems (Domínguez-González & Delgado-Martín, 2022), involved secondary school students. In addition, papers such as Training in mathematics education from a sustainability perspective: A case study of university teachers' views (Moreno-Pino et al., 2022) and Teachers candidates' awareness of sustainable development (Aydin & Keles, 2021), used secondary teacher trainees on the mathematics education course carried out in the University. Though these papers were valuable to the study, they contributed more to the higher education level than the secondary school education level.

## Research Question 1

This study aimed to answer the research question: "What teaching conditions moderate effective implementation of mathematics for sustainable development at the lower secondary school level?" The results of the study show that some studies revealed conditions that moderate effective implementation of MSD in lower secondary schools teaching such as curriculum (Kim & Pang, 2022; Santamaría-Cárdaba et al., 2021; Tatto, 2021), teacher training and continuous professional development (Aydin & Keles, 2021; Domínguez-González & Delgado-Martín, 2022; Husamah et al., 2022; Tatto, 2021), mathematics resources(Kim & Pang, 2022; Ningsih & Juandi, 2019), nature of math content (Domínguez-González & Delgado-Martín, 2022; Kim & Pang, 2022; Ningsih & Juandi, 2019; Tatto, 2021), interdisciplinary teaching (Domínguez-González & Delgado-Martín, 2022; Renert, 2011), and assessment (Domínguez-González & Delgado-Martín, 2022). Several studies have also focused on MSD implementation processes that develop students' and teachers' skills, namely: The structure of math tasks and activities (Domínguez-González & Delgado-Martín, 2022), teaching approaches (Hopkinson & James, 2010), and math models for sustainable teaching (Renert, 2011; Zhang, 2022).

## Curriculum Reform and Analysis

Husamah et al. (2022), in their systematic review of sustainable development, identified the need for curriculum reform and analysis as the key to the successful implementation of math teaching for sustainability. This is so because the curriculum indirectly contains subject content that can easily be linked to ESD, which, in turn, mathematics teachers can utilise to promote ESD domain integration in mathematics learning (Ningsih & Juandi, 2019). The difficulty associated with curriculum articulation by mathematics teachers is consistent in the studies by Santamaría-Cárdaba et al. (2021) and Tatto (2021), which found secondary mathematics teachers facing difficulties in the integration of SDGs in teaching some of the school curriculum topics. According to Husamah et al. (2022) and Kim and Pang (2022), curriculum analysis is only possible if teachers' sustainability competencies are updated and aligned with ESD content and instruction. Therefore, in a curriculum for a sustainable context, teachers should conduct research to include the most

**Table 2. S**howing the ESD domains and their corresponding

| Authors | Social-cultural | Environment | Economy |
|---|---|---|---|
| Ningsih & Juandi (2019) | human rights, peace and human security, gender equality, cultural and intercultural diversity, health, HIV & AIDS, governance | natural resources (water, energy, agriculture, and biodiversity), climate change, rural development, sustainable urbanization, disaster prevention, and mitigation | poverty reduction, corporate responsibility, accountability, and understanding and reorientation of the market economy |
| Kim and Pang (2022) | Human rights: Human respect, human rights respect<br>Peace and security: Understanding nonviolence, nonviolence activities, dialogue and compromise, safety education<br>Cultural diversity: Respect for cultural diversity<br>Social ethics: Correct social ethics, readjustment of legal systems<br>Human health: Exercise, health, disease prevention, and treatment, obesity, drugs, AIDS, food safety and security<br>Gender: Gender discrimination issues<br>Media literacy: Information communication ethics, media literacy<br>Globalization and international responsibility: Understanding globalization, problems of globalization, international solutions<br>Population: Population growth, population distribution by region | Natural resources: water, atmosphere, soil, minerals, plants, animals, natural scenery, natural resources conservation<br>Energy: Energy types, renewable energy, energy conservation<br>Climate change: Global warming, greenhouse gases, abnormal climate<br>Biodiversity: Ecosystem equilibrium, endangered species, biodiversity, biological conservation<br>Environmental problems: Awareness of environmental issues, efforts to solve environmental problems, nature of environmental problems<br>Urban and rural environments: Urban functions, urban problems, the aging of villages, improvement of residential environment, environmental problems, rural-urban gaps<br>Disaster: Types of disasters, causes, and solutions of disasters<br>Traffic pollution: Traffic pollution, traffic safety, environmentally friendly traffic solutions | Sustainable food production: Eco-friendly production, waste management, sustainable agriculture, eco-friendly agricultural products<br>Sustainable consumption: Green consumption,<br>Sustainability of companies: Corporate ethics, corporate responsibilities and duties<br>Market economy: Understanding market economy, sustainable commercial sales |

current information in the activities and test the effectiveness of the method used during the teaching-learning process (Domínguez-González & Delgado-Martín, 2022).

The results provided pressing issues at the international level linked to the three Sustainable Development domains: socio-cultural, environmental, and economic (see **Table 2**). The detailed description of the global issues in the three domains offers opportunities to mathematics educators in Africa and Uganda, specifically to enrich their curriculums in promoting SDGs and SD teaching.

## Teacher Training and Continuous Professional Development

Regarding teacher training, strengthening teachers' competencies toward sustainable teaching is identified as key (Aydin & Keles, 2021; Husamah et al., 2022). Also, Tatto (2021) identified priority areas for mathematics teachers if they are to implement MSD teaching: For pre-service teachers, teacher training institutions should focus on mathematics content knowledge (MCK), mathematics pedagogical content knowledge (MCPK), teaching for diversity, teaching for reflective practice and teaching for improving practice. For the in-service teachers, the focus should be directed to MCPK and resources for quality teaching. In addition, the curriculum should be part of the menu for continuous professional development (CPD) advocated for in-service teachers in the implementation of SDGs teaching. Our analysis shows that CPD for in-service mathematics teachers provides the opportunity for curriculum initiation, curriculum interpretation, and curriculum implementation of issues that have a significant impact on SDGs in lower secondary schools. It should be noted that CPD organisers are critical in identifying curriculum issues that teachers value according to experience. Experienced teachers' participation depends on the motive of the CPD since they don't value them much (Wagner & Davis, 2010).

## Mathematics for Sustainable Development Integrated Content

Regarding mathematics content for sustainability, Santamaría-Cárdaba et al. (2021) investigate the importance of mathematics content in sustainability integration by mathematics teachers in Spain. They found out that that out of the 17 SDG-related content (fair trade, humanitarian Aid, responsibility consumption, anti-globalisation movement, ethical purchasing, cultural diversity, sustainable human development, forms of citizen participation, economic inequality in the world, poverty, cooperation for development, social movements, gender equality, globalisation, solidarity, intercultural relations), mathematics teachers scored higher in only three namely: Gender equality (77%), cultural diversity (57%), and solidarity (50%) this was so because they were found to be emphasised at all education levels: primary, secondary and higher institutions.

Similarly, Kim and Pang (2022) rated content that was easy to connect to math as natural resources, climate change, and environmental problems for the environment dimension; peace and security, human health, and population for the social dimension; and sustainable food production, consumption and narrowing the gap between the rich and the poor for the economic dimension. Furthermore, mathematics content that fitted well in teaching the different SDGs included topics such as fractions and percentages (Kim & Pang, 2022); number operations, data and possibilities such as graphs, organisation of data, pie charts (Kim & Pang, 2022; Tatto, 2021), geometry, measurement, algebra, and functions (Tatto, 2021), statistics and systems of linear equations (Ningsih & Juandi, 2019).

**Table 3.** Mathematics tasks for sustainability learning from the Japanese and Korean textbooks

| Country | Topic | Activity topic | Contents of activity | Relation to ESD |
|---|---|---|---|---|
| Korea | Addition and subtraction | Exploratory mathematics: What should we do to live a healthy life? | Calculate how many calories we have in eating snacks. Create exercise plans | Create exercise plans for a healthy lifestyle considering the date, time, calories consumption, and types of exercise. |
| | Arrangement of Data | Exploratory mathematics: Which drink should we choose? | Investigate how much sugar is in different beverages. Represent the data in a pictogram. Share what you felt through the activity. | Recognize the amount of sugar in beverages. Pledge to live a healthy life by drinking beverages with less sugar |
| | Ratio and Rate | Challenging mathematics: Let's read the environment. through mathematics | Check the reuse status of bottles. Calculate the increase in empty bottle deposits and pose a problem | Find the rate of reuse of empty bottles. Commit to reusing bottles to protect the environment |
| Japan | Percentages | A story in arithmetic: Lost Forest | Calculate the percentages of forest decline by looking at the areas of forest in 2000 and 2005 in various regions Forecast area of the forest in 2020 based on the data. | Recognize the benefits of forests. Anticipate the future of the forest. Have a mindset to protect the forest. |
| | Various graphs | Various graphs | Interpret the graphs about the population of Japan in 1970 and 2005 Share what you noticed and predict the future of society | Understand the social changes: the increase of low birth rate and the increase of aging. Have a mindset for a sustainable society. |
| | | Waste reduction and carbon dioxide | Analyse the data about garbage presented in a bar graph, an angled line, and a circle graph. Calculate the number of cedar trees based on the amount of carbon dioxide | Understand the seriousness of the garbage problem. Confirm that incineration of waste leads to the generation of carbon dioxide, which is the main cause of global warming. |
| | | Rain is a valuable resource | Interpret data about daily water use at home presented in a bar graph, a circle graph, and a table. Calculate the amount of rainwater stored. | After calculating how much water is used at home and how much rain is stored, make a commitment to use water carefully. |

Kim and Pang (2022) also provided mathematics tasks that relate to sustainability in their study of textbooks in the three Asian countries (Japan, Korea, and Singapore). The tasks in Japanese and Korean textbooks in **Table 3** included an ESD statement under the "Relation to ESD" strand, showing the expected student's tasks to perform during the activity. In addition, the ESD statements are appropriately blended with the contents of the activity, hence shaping the MSD discussion during the teaching and learning process. The information presented in the table by the two countries is important for Mathematics educators in Uganda and Africa in terms of the approach for each topic, which can be used to implement MSD lessons.

## Teaching Mathematics Combined with Other Subjects

The review also revealed that ESD, through mathematics as a core subject, is best addressed through the interdisciplinary approach by linking it with other subject experts (Domínguez-González & Delgado-Martín, 2022). The subjects identified include a combination of mathematics and physics, mathematics and economics, and mathematics and physical education under the interdisciplinary approach (Domínguez-González & Delgado-Martín, 2022). Mathematics, science, and social studies, the three-subject combination, are cited under the transdisciplinary approach (Renert, 2011), and Science, Technology, Engineering, and Mathematics (STEM) under the multidisciplinary approach (Nguyen et al., 2020).

## Sustainable Development Goal Content Integrated Instructional Practices

The moderating conditions under teachers' instructional practices towards SDGs are presented to include a sample of sustainable development-compliant lesson structure, real-life instructional resources, teacher attributes, and assessment.

Concerning sustainable lesson structure, Domínguez-González and Delgado-Martín (2022) provide a sample of the MSD-based lesson plan template, which includes aspects such as a title, math content, SDGs, and a comprehensive task statement. This entails context, data, information, and links for understanding that prompt students to make decisions from the calculations they make. Another instructional practice is identified by Tatto (2021), who uses Cochran-Smith's description of what quality teaching entails. He provided attributes the teacher should have, namely, the ability to represent complex knowledge in accessible ways, ask good questions, form relationships with students and parents, collaborate with other professionals, and interpret multiple data sources.

Regarding the nature of resources that enhance math teaching for sustainability, Widiati and Juandi (2019) used UNESCO guidelines for creating mathematics curriculum resources. The resources were characterised to include real context, current issues, value, access to data, human activity, interdisciplinarity, sensitivity to marginalization, openness to dialogue, trust, access, and use of technology.

**Table 4.** Sample template used by Taiwan elementary school teachers

| Level 1: Goal | Level 2: Teaching scopes | Level 3: Indicators | Level 4: ESD dimensions |
|---|---|---|---|
| Sustainable development | Ecology, energy conservation, waste reduction, and health | -Biodiversity<br>-Vegetation amount | Environment |

Assessment is another important aspect that was identified in teaching for sustainability. Students' MSD-based activities are assessed and measured by students' degree of participation, their proposals, and their oral and written reflections to reveal their dedication and commitment to the content (Aydin & Keles, 2021).

Kim and Pang (2022) presented Liu et al. (2020) evaluation framework in **Table 4** used by Taiwan elementary school teachers that contain goals, teaching scope, and indicators categorised according to the SD dimension. This is a user-friendly template that can be used as an assessment guide by mathematics educators in Uganda when aligning curriculum content to fit into the three ESD dimensions (economy, social, or environment).

In line with mathematics modelling tasks, Delphi's evaluation model of mathematics modelling and teaching by Zhang (2022) in **Table 5** was found useful and can be adapted by Mathematics educators and curriculum developers when assessing MSD teaching. The model evaluates four aspects: The topic /specific subject content, the process, the teaching, and the learning. The attributes associated with the first two (topic and process) are key in guiding the Modeling of MSD tasks. The monitoring teaching stage is for teacher support and improvement of the MSD tasks. The cooperative learning stage is a teacher competence-based stage. This stage is important for the successful implementation of interdisciplinary Mathematics integration required for sustainable teaching.

Finally, the results presented samples of SDGs-integrated mathematics tasks by Domínguez-González and Delgado-Martín (2022) that can be used as guiding MSD modelling tasks (see **Table 6**). The task statement is so detailed that one gets to focus on the global problem ahead of us. In addition, SDG 17 in the activity blends well, making everyone's concern if the plastic problem is to be solved. The mathematics component that is embedded in the task at the end completes the MSD task that Mathematics educators in Uganda can take advantage of during the MSD modelling task- process.

**Table 5.** Delphi's model of mathematical modelling teaching evaluation

| Modelling aspects | Indicators |
|---|---|
| Modeling topics | Relevance |
| | developmental |
| | attractive |
| Modeling process | build the model |
| | solve the model |
| | improve the model |
| Modeling monitoring-teaching | strategy guide |
| | administration of quality supervision |
| | comprehensive evaluation |
| Cooperative learning | to form a team |
| | clear division of labour |
| | effective cooperation |

**Table 6.** MSD task presented by Domínguez-González and Delgado-Martín (2022)

| |
|---|
| ACTIVITY: Plastic islands in an ocean of us all.<br>SDG 14: Life below water.<br>SDG 17: Partnerships for the goals. |
| Math contents: Linear functions, exponential functions, and compound interest formula |
| Task Statement:<br>Even though they do not show up on geography maps nor are they visible as real islands, five gigantic ever-growing clusters of plastics and microplastics are currently infecting our oceans, contributing to global warming and threatening to lead a great number of sea life species to extinction. The gargantuan volume they take has led them to be called "the seventh continent", or also "the plastic continent". All of this huge marine debris is the result of the accumulated production of plastics over the years, where newly produced plastics add up to accumulated past ones due to the low degradability and the strong.<br>Given the cumulative global plastics production, the numbers for the years:1965 is 112 million tonnes; 1975 is 480 million tonnes; and 2015 is 7.82 billion tonnes.<br>It is known that the formula for an exponential growth model can be approximated to one of the compound interests, $A = P \cdot (1 + r)^t$, with $A$ being the final quantity, $P$ the initial quantity, $r$ the growth rate (or percentage), and $t$ the time (in years).<br>Calculate: The resulting growth rate from 1965 to 2015. The probable quantity is to be expected for 2025 if growth were to stay at that rate.<br>Connecting the 1965 and 1975 values with a straight line, determine the relationship between the real value from 2015 and the one that would have resulted from a linear growth model (the value the straight line would have arrived at). |

## Research Question 2

The study also aimed to answer a second research question: "What strategies are used to develop students' competencies during MSD lesson implementation?" The study revealed procedures and strategies used in developing students' competencies. Domínguez-González and Delgado-Martín (2022) describe six key competencies related to MSD teaching, namely:

Mathematics competency: Knowing and using different mathematics elements, interpreting graphs, organising information using mathematical procedures, and applying problem-solving strategies.

Linguistic communication: Ability to understand both written and oral texts and use of language skills to search for information.

Digital competence: Use of technology to facilitate daily life and transmit diverse information.

Social competence: The ability to promote actions with a social purpose and recognise the diversity of opinions and ideas.

Sense of initiative and entrepreneurial spirit: The ability to convey with enthusiasm and confidence possibilities to achieve the SDGs.

Learning how to learn: The ability to apply strategies to improve creativity and critical thinking, evaluating and becoming aware of the learning processes.

The transformation-oriented approach in modelling mathematics tasks was identified as a strategy with the ability to model mathematics tasks that can promote the above students. competencies. Renert (2011) uses Sterling and Orr's (2001) model to categorise mathematics content towards sustainable development learning using the three levels of learning: accommodation at the lower level, reformation moderate level, and transformation at the highest level. According to Sterling (2004), the accommodation level attempts to integrate, but the status quo in curriculum implementation remains unchanged. The reformation level integrates sustainability ideas into the curriculum with significant change. In transformative learning, learning engages the whole person and changes an individual's values and beliefs. Kim and Pang's (2022, p.11) transformative example: "Investigate the amount of sugar in various beverages, represent the data on a pictograph, and determine the drink they should prefer to live a healthy life".

The task shows the value of learning the concept, empowers learners, and prompts creativity in the learners.

Student's competencies acquisition of 21st-century competencies of critical thinking, creativity, communication, and collaboration teaching are enhanced by MSD teaching (Widiati & Juandi, 2019). Aslam et al. (2021) used reciprocal teaching and conducted a post-test-only quasi-experiment intervention for 8 weeks, working with two sixth-grade classes at a public secondary school in Pakistan. This approach involved five procedures: predicting, clarifying, solving, summarising, and recording. The results showed that reciprocal teaching improved critical thinking, reasoning, and in-depth understanding of mathematics word problems. Nguyen et al. (2020) identified pedagogical approaches that enhance students' acquisition of specific competencies for SD and contribute to the achievement of SDGs, namely:

1. Problem-based learning (promotes critical thinking, students use similar previous knowledge and experiences to solve problems);
2. project-based learning sometimes referred to design-based learning approach (activates students' creativity and innovativeness); and
3. cooperative learning approach (builds collaborative skills which develop positive attitudes and behaviour amongst students).

## DISCUSSION OF RESULTS

The aim of the study was to find the moderating conditions that enhance the effective implementation of MSD and the strategies that strengthen the development of students' competencies as a result of MSD implementation at the lower secondary school level. Based on these aims, we used a scoping review of the concept of Mathematics for sustainable development for published articles between 2005 and 2022. The results revealed factors such as curriculum reform and analysis, teacher training and CPD, sustainable development integrated content, and a combination of mathematics with other subjects as key moderating factors that promoted teaching MSD discussed in the next two sections.

### Moderating Conditions Promoting Mathematics for Sustainable Development Learning

The results indicate that there is a strong relationship between curriculum and teacher-effective content implementation. The two are connected by the content within textbooks mathematics teachers use as the main instructional resource. One could easily argue that the obvious practical implication of this study is that it proposes utilising textbook developers to include SDG-related mathematics content that promotes mathematics teaching for sustainable development. This is seen as an entry point into the mathematics teachers' practices.

Teaching and learning that integrate sustainable development focus on the specific emphasis on the SDGs (Kopnina, 2018). Karjanto and Acelajado (2022) applaud the curriculum for promoting sustainable learning by intentionally infusing competencies such as critical thinking, problem-solving, and collaboration. Renert (2011) provides a mathematics and ecological sustainability example where for a kilogram of weight gain, a cow requires 7 kgs of grain while 2 kgs of grain for chicken, which is three and half times the resources needed for a cow as compared to chicken. This example is not only required in designing curricula but also shows the importance of interdisciplinary strategy, where content borrowed from other fields makes mathematics problems meaningful.

However, there is complexity in the integration of the SDGs into the curriculum (Renert, 2011); teachers and curriculum designers should think through activities that enhance learners' attainment of skills that lead to the chosen SDG (Leal Filho et al., 2019). In addition, the curriculum should be part of the menu for CPD advocated for in-service teachers in the implementation of Sustainable Development Goals teaching (Vásquez et al., 2023). Our analysis predicts that CPD for in-service mathematics teachers provides the opportunity for curriculum initiation, interpretation, and implementation of issues that have a significant impact on SDGs in lower secondary schools. SD integration into the curriculum and subject-specific requires support in the training of teachers as a component (Vilmala et al., 2022).

The fact that novice teachers prefer CPD content about the curriculum, while experienced teachers prefer CPD content about curriculum design (Anggraeni & Rachmajanti, 2021; Wagner & Davis, 2010) provides a strong signal for curriculum reforms on SDG integration by when designing CPD programs for teachers. CPD organisers should be critical in identifying teacher gaps in implementing curriculum on issues that teachers value according to their experience.

As regards MSD integrated content, it was found that mathematics teaching related to environment, social, and economic dimensions is easy to incorporate. Teachers find it easy to use issues that are more pronounced as national concerns. Santamaría-Cárdaba et al. (2021) identified gender equity as the most pronounced SDG in mathematics teaching in Spain. This is evidenced by Spain's position on the gender equity index in 2013 at 54 (between 1 inequality and 100

equality), higher than Austria, Italy, Germany, Greece, Luxemburg, and Portugal (Bustelo, 2016). This implies that concepts emphasised in the curriculum are reflected at the national level. According to Kioupi and Voulvoulis (2019), the integration of sustainable ideas and practices is easier when included in educational curricula and policies. Subsequently, subject content for sustainable learning should be able to address students' needs and wants (Chaikovska & Levchyk, 2022).

The results also indicated that teaching mathematics by borrowing content from other subjects allows a broad scope for teachers to pick mathematics activities that enhance sustainable development learning. According to Bassachs et al. (2020), interdisciplinary approaches led to higher student achievement in terms of concept understanding, reflective practice, and critical thinking. Similarly, Nordén (2018) found that although teachers contributed to the interdisciplinary project, they found these projects challenging. However, interdisciplinary teaching is associated with problems such as teacher overload and the inability to apply mathematics combined with other subject areas (Madlung et al., 2011). By 'overload', means more planning since teachers in Uganda and elsewhere qualify in clearly specified teaching subjects. Thus, the 'other subjects' are perceived as new content that brings additional work. This implies that teachers of different subject areas should be consulted when designing mathematics activities that promote mathematics for sustainable development learning to ease the burden of the 'overload'.

### The Strategies that Promote Students' Competencies Through Mathematics for Sustainable Development Learning

The results indicate that there is a strong relationship between pedagogical approaches (such as reciprocal teaching, problem-based learning, project-based learning, and cooperative learning approach) and students' competence acquisition. Project-based learning motivates students and promotes critical thinking (Remijan, 2017); it increases learners' activeness during discussions and their willingness to do assignments (Pahmi et al., 2022). Problem-based learning pedagogy was found to be effective in the attainment of problem-solving skills, with an average score of 52.96 on the pre-test and 79.84 scores on the post-test (Pradipta et al., 2021). This implies that mathematics teachers should devote their time to learning these pedagogies so that students benefit from the different competencies that come with their use.

Transformative mathematics content indicates that coming up with this kind of activity takes a mathematics teacher to the highest level of content knowledge formulation required to implement MSD lessons. It is therefore arguable that coming up with transformation-oriented mathematics activities is synonymous with promoting all the desired 21st-century competencies - critical thinking, creativity, communication, and collaboration. According to Johnson and Olanoff (2020), transformative learning leads to a deeper understanding of mathematics concepts and promotes a positive attitude toward mathematics.

## CONCLUSION

The limited studies about MSD at the secondary school level showcase a knowledge gap that needs to be filled. This scoping review paper provides answers to conditions responsible for the effective implementation of MSD learning at the lower secondary level and the current adaptation classroom practices that enhance students' competence acquisition as a result of learning mathematics for sustainability, more so in Uganda and Africa at large.

This scoping review consequently identified curriculum reforms that are aligned to sustainable teaching at secondary teacher education institutions and secondary schools' level as key to promoting MSD teaching. The study, therefore, recommends the implementation of the Uganda National Teacher Policy for its promotion of competencies: curiosity, critical thinking, creativity, confidence, collaboration, and communication (Government of Uganda, 2019). This is a crucial step in the development of a skilled teaching force that will eventually lead to the effective implementation of Uganda's lower secondary school CBC curriculum. This is in line with Uganda's Vision 2040, which focuses on meeting Uganda's challenges of inadequate skills amongst the educated human resources (Balyejjusa, 2015).

## LIMITATIONS

This scoping review is limited to the English language; future studies are encouraged to include books, book chapters, and dissertations written in English and other languages. Secondly, though Scopus is one of the respected databases used alongside two different databases in generating articles in this scoping review, more educational-related databases should be used in future studies. Most of the reviewed literature was non-experimental studies. Only one experimental study, titled Arousing early strategic thinking about SDGs with real mathematics problems, was an experimental study. The authors propose more experimental studies and case studies for teaching MSD at the secondary school level in Ugandan classrooms to enhance understanding of the MSD concept in practical application.

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# APPENDIX

**Table A1.** Articles included in the Mathematics for Sustainable Development in lower secondary scoping review

| Author(s) | Year | Title of article | Source | Doi number |
|---|---|---|---|---|
| Aslam, S., Saleem, A., Hali, A. U., & Zhang, B. | 2021 | Promoting sustainable development in school classrooms: Using reciprocal teaching in mathematics education | *TEM Journal, 10*(1), 392-400 | https://doi.org/10.18421/TEM101-49 |
| Aydin, S., & Keles, P. U. | 2021 | Teachers' candidates' awareness of sustainable development | *Shanlax International Journal of Education, 9*, 221-227 | https://doi.org/10.34293/education.v9iS1-May.4015 |
| Domínguez-González, R., & Delgado-Martín, L. | 2022 | Arousing Early Strategic Thinking about SDGs with Real Mathematics Problems | *Mathematics, 10*(9), Article 1446 | https://doi.org/10.3390/math10091446 |
| Hopkinson, P., & James, P. | 2010 | Practical pedagogy for embedding ESD in science, technology, engineering and mathematics curricula | *International Journal of Sustainability in Higher Education, 11*(4), 365-379 | https://doi.org/10.1108/14676371011077586 |
| Husamah, H., Suwono, H., Nur, H., & Dharmawan, A. | 2022 | Sustainable Development Research in Eurasia Journal of Mathematics, Science and Technology Education: A Systematic Literature Review | *EURASIA Journal of Mathematics, Science and Technology Education, 18*(5), Article em2103 | https://doi.org/10.29333/ejmste/11965 |
| Kim, J., & Pang, J. | 2022 | An Analysis of Sustainable Activities in Japanese, Korean, and Singaporean Elementary Mathematics Textbooks | *EURASIA Journal of Mathematics, Science and Technology Education, 18*(2), Article em2080 | https://doi.org/10.29333/ejmste/11651 |
| Moreno-Pino, F. M., Jiménez-Fontana, R., Domingo, J. M. C., & Goded, P. A. | 2022 | Training in mathematics education from a sustainability perspective: A case study of university teachers' views | *Education Sciences, 12*(3), Article 199 | https://doi.org/10.3390/educsci12030199 |
| Nguyen, T. P. L., Nguyen, T. H., & Tran, T. K. | 2020 | STEM education in secondary schools: Teachers' perspective towards sustainable development | *Sustainability, 12*(21), Article 8865 | https://doi.org/10.3390/su12218865 |
| Ningsih, S. Y., & Juandi, D. | 2019 | Achievement of ESD through mathematics learning | *Journal of Physics: Conference Series, 1157*, Article 042056 | https://doi.org/10.1088/1742-6596/1157/4/042056 |
| Renert, M. | 2011 | Mathematics for life: Sustainable mathematics education | *For the Learning of Mathematics, 31*(1), 20-26 | — |
| Santamaría-Cárdaba, N., Martins, C., & Sousa, J. | 2021 | Mathematics Teachers Facing the Challenges of Global Society: A Study in Primary and Secondary Education in Spain | *EURASIA Journal of Mathematics, Science and Technology Education, 17*(4), Article em1955 | https://doi.org/10.29333/ejmste/10806 |
| Schell-Straub, S. | 2013 | Mathematics Education Meets Development Education: The Competency 'Mathematical Modelling' combined with Global Skills and Competencies in a Secondary School Project in Germany | *International Journal of Development Education and Global Learning, 5*(1), 7-31 | — |
| Widiati, I., & Juandi, D. | 2019 | Philosophy of mathematics education for sustainable development | *Journal of Physics: Conference Series, 1157*, Article 022128 | https://doi.org/10.1088/1742-6596/1157/2/022128 |
| Zhang, Z. | 2022 | Construction of Mathematical Modeling for Teaching Evaluation Index System Based on the Delphi AHP Method | *Scientific Programming*, 1 - 8 | — |