Cogent Education

ISSN: 2331-186X (Online) Journal homepage: www.tandfonline.com/journals/oaed20

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To cite this article: Ismael Gaanya, Marjorie Sarah K. Batiibwe & Bettina Dahl (2026) Teachers' instructional practices reflecting Mathematics for Sustainable Development implementation in secondary schools in Uganda, Cogent Education, 13:1, 2677421, DOI: 10.1080/2331186X.2026.2677421

To link to this article: https://doi.org/10.1080/2331186X.2026.2677421

COGENT EDUCATION
2026, VOL. 13, NO. 1, 2677421
https://doi.org/10.1080/2331186X.2026.2677421

CURRICULUM & TEACHING STUDIES | RESEARCH ARTICLE

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Teachers' instructional practices reflecting Mathematics for Sustainable Development implementation in secondary schools in Uganda

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ABSTRACT

This paper explores the mathematics teachers' practices during the implementation of Mathematics for Sustainable Development (Math4SD) in lower secondary schools in Uganda. The study used a qualitative case study research design with an embedded professional development intervention. Data was collected using lesson observation field notes, interviews, and students' focus group discussions. The study adopted the theory of learning levels of accommodation, reformation, and transformation to evaluate teachers' knowledge of SDGs integration in modelling Math4SD tasks when teaching business mathematics. In addition, 21st-century skills such as critical thinking, creative thinking, communication, and collaboration, associated with Math4SD teaching, were analysed. The study findings revealed that collaboration skill was the most exercised skill during the Math4SD teaching and learning process. Considering teachers' Math4SD modelling practices, the transformation level was the most challenging for teachers to apply. The findings further revealed that teachers' Math4SD tasks were highly related to the social and economic SD domains, possibly due to the business mathematics-related topics teachers used. The study therefore recommends further research on integrating the SDGS in Mathematics at the secondary school level, using topics unrelated to business mathematics.

ARTICLE HISTORY
Received 7 June 2025
Revised 4 February 2026
Accepted 16 May 2026

KEYWORDS
Mathematics for Sustainable Development; Instructional practices; Uganda; secondary schools; competence based curriculum

SUBJECTS
Social Sciences, Education, Classroom Practice, Assessment & Testing, Education, Teaching & Learning

JEL CLASSIFICATIONS
Secondary Education; Teaching Practice - Education; Education; Development Studies; Environment; Social Work; Urban Studies; Social Sciences; Sustainability Education; Training & Leadership; Education; Social Sciences; Classroom Practice; Education; Social Sciences

1. Introduction

This study introduces the Mathematics for Sustainable Development phenomenon at Uganda's lower secondary school level through evaluating mathematics secondary school teachers' practices in implementing SDGs-integrated mathematics lessons. Mathematics for Sustainable Development (Math4SD) is defined as 'efforts to inculcate the value of character, skills, attitudes, and knowledge through the application of mathematics learning in the field of environment, social, culture, and economics so that learning mathematics becomes consciously useful in sustaining their lives sustainably and support the achievement of Sustainable Development Goals' (Widiati & Juandi, 2019, p. 2). In this study, the

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Supplemental data for this article can be accessed online at https://doi.org/10.1080/2331186X.2026.2677421.

Math4SD phenomenon is conceptualised as Mathematics teaching that integrates the 17 SDGs. Ningsih and Juandi (2019) describe Math4SD as indirectly embedded in mathematics curricula, only waiting for teachers to activate it. The inclusion of the cross-cutting issues into Uganda's Competence-Based Curriculum at the lower secondary level becomes the entry point for integrating SDGs in Mathematics education. Cross-cutting issues are attached to the three Math4SD perspectives of; social-cultural (human rights, peace, human security, gender equality, understanding cultural and intercultural diversity, health, HIV, governance); environment (water, energy, agriculture, biodiversity, climate change, rural development, sustainable urbanization, disaster prevention); and economy (poverty reduction, accountability, reorientation of the economy market (Ningsih & Juandi, 2019).

Existing studies about Math4SD, such as Philosophy of Mathematics Education for Sustainable Development (Widiati & Juandi, 2019) and Achievement of Education for Sustainable Development through Mathematics Learning (Ningsih & Juandi, 2019), reviewed the literature. Competencies of Education for Sustainable Development Related to Mathematics Education in Senior High School (Yuniarti et al., 2019) administered a survey on high school teachers. All the studies were carried out in the Asian context. For instance, Gaanya et al. (2025) carried out a scoping review of existing literature on Math4SD pedagogies from 2005 to 2022, using large data sources (ERIC, EBSCOhost, and Scopus), which yielded only 14 articles about the phenomena at the lower secondary school level. The majority of the articles were published in Europe and Asia. Unfortunately, there was no single study undertaken in Africa, although there was abundant research about SDG3 of good health and well-being in Africa (Sweileh, 2020). Thus, the study would enable researchers to acquire working definitions and conceptual boundaries in this emerging research area, and the practical realities of its implementation in Ugandan secondary schools.

The study addresses the following research questions:

i. How do lower secondary school mathematics teachers implement SDGs-integrated lessons?
ii. What skills do learners achieve through SDGs-integrated mathematics lessons?

1.1. Theoretical framework

Mathematics teachers' successful integration of crosscutting issues/SDGs in teaching mathematics at the lower secondary school level requires them to have interconnected knowledge of the three domains of ESD (social, economic, and environment), the 21st-century skills (AlAli et al., 2023) and the sustainable development learning levels of accommodation, reformation, and transformation (Sterling & Orr, 2001). Teachers' responses at the accommodation level are basic in learning about change. Sterling (2004) reveals that during the accommodation level, an attempt is made 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, the learning engages the whole person and changes an individual's values and beliefs, giving them meaningful lives (Dembereldorj et al., 2024).

2. Literature review

2.1. Structure of Mathematics for Sustainable Development teaching

According to Widiati and Juandi (2019), 'Mathematics teaching based on ESD requires students not only to think mathematically but have sensitivity to the problems found in the surrounding environment, especially in the social, economic, and environmental fields' (p. 6). UNESCO (2017) argues that mathematics curriculum developers, when developing SD content, should consider real contexts, current issues, social complexity, values, access to data, human activity, foregrounding context, interdisciplinary approaches, sensitivity to marginalization, opening dialogue, courage, trust, access, and the use of technology. Additionally, UNESCO (2012) proposes a focus on knowledge, issues, skills, perspectives, and values.

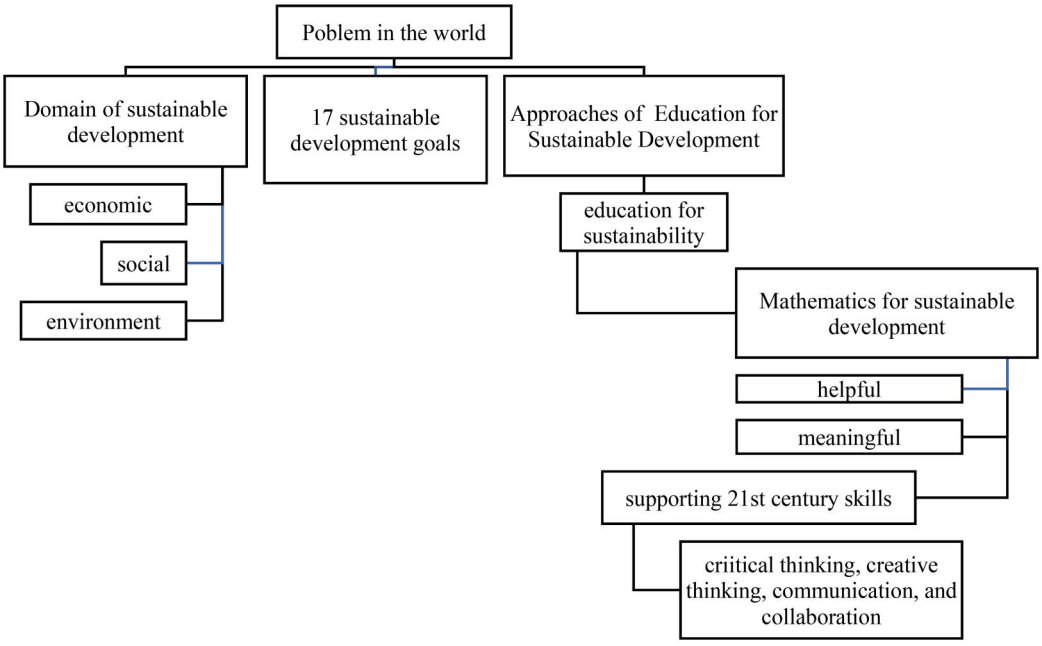

Figure 1. Mathematics for Sustainable Development framework (adapted from Widiati & Juandi, 2019).

McKeown et al. (2002) envisages five components of ESD as; acquisition of knowledge from different disciplines in understanding the principles of SD, skills that enable people to successfully survive after they leave school, values that are modeled, explained, and analysed for understanding one's view and other people's viewpoints, perspectives based on history and prediction of the future in line with SD, and issues focused on social, economic, and environmental aspects that threaten Sustainable Development of the world. Su et al. (2023) view these five components differently and take knowledge to include natural, social, and human sciences; skills involve practical skills for sustainable living; perspective looks at the global and local context of problems; values include ethical teaching and analysis of issues; and problems involve social, economic, and environmental issues.

Widiati and Juandi (2019) provided a visual schema (Figure 1) illustrating the interaction of these five aspects and the role of teaching mathematics in promoting sustainability.

The schema shown in Figure 1, the Math4SD concept, is rooted in the approaches of ESD. Math4SD should focus on teaching meaningful and helpful content. The three components of knowledge, perspectives, and values described by Su et al. (2023) and McKeown et al. (2002) are useful in developing meaningful and helpful Math4SD content. The schema further identifies 21st-century skills as skills that teachers should develop in students during teaching for sustainability since mathematics plays a role in understanding the world due to its orderliness (Kuznetsova et al., 2021).

AlAli et al. (2023) in their study to ascertain the degree to which STEM-based teaching aligns with SDGs, surveyed 171 Saudi Arabian educators (126 teachers and 45 educational supervisors), with 85 males and 86 females, and recommended the adoption of STEM-based pedagogical approaches (coordination, complementary, connection, communication, and blended integration) to achieve the SDGs integration in teaching. Under coordination integration, content of one subject is presented with another subject, while in complementary integration, content of a subject is used to supplement basic content in another. Connection integration presents a central topic, containing two subjects to enhance students' understanding of the differences and similarities between the two. Communication integration uses one discipline to link other disciplines with it. Blended integration involves implementing pivotal topics that require the merging of two or more disciplines. Interdisciplinary integration into mathematics enables students to demonstrate a high sense of productivity when other subjects are integrated into mathematics (Staats, 2014).

Karjanto (2023) observed that mathematics modelling can be divided into two categories: Mathematics modelling that deals with learning about sustainability (students gain knowledge about

various aspects of sustainability in addition to relating to economy, society, and environment) and Mathematics modelling for sustainability learning in education (learning that lasts), which involves knowledge that requires continuous renewal and improvement after graduation. The author provides a mathematics modelling task example (In spring 2017, the Earth's human population surpassed 7.5 billion. What do you imagine was the population of Earth two thousand years ago, at the beginning of the Common Era?), which demographers, scientists, and historians can use, which falls under learning that lasts or requires continuous renewal and improvement. This distinction helps teachers in modelling appropriate sustainable development tasks.

Alsina and Calabuig's (2019) model of sustainable development integration in Mathematics teaching describes five key aspects for teachers to develop students' skills and competencies. The aspects are: connection environment, didactic disciplinary knowledge, reflective and critical thinking, the learning needs of children, and the incorporation of sustainability into the curriculum.

When linking with the environment, teachers should be able to determine what is relevant and transfer it to teaching situations, making mathematics education fulfill the role as an agent of social and cultural change. While under didactic disciplinary knowledge, teachers should strive to achieve a good command of math content. They should attach importance to lifelong learning for their CPD. Yet in reflective and critical thinking, teachers engage in autonomous learning that self-regulates the need to change, improve, search for solutions, and evaluate themselves. In attending to Children's learning needs, teachers should acquire strategies so that education can enhance students' understanding of the relationship between the environment and mathematics. While for curriculum environmentalisation, the teacher education curriculum should focus on SD to help future teachers select curriculum knowledge with sustainability criteria.

2.2. Mathematics for Sustainable Development teaching in Uganda

The Ugandan school system has seven years of primary education, with six years as the official legal school entry age. Secondary education is divided into two: four years of Ordinary level, and two years of Advanced level. After secondary education, students join higher education institutions for a three to five-year program. Like many other African school systems, Uganda's structure was inherited from Britain in 1962 when self-government was attained. During the 1960s, 1970s, and 1980s, Uganda adapted curricula and educational materials from the USA and Britain. However, after the political and economic turmoil of the 1970s and 1980s, along with a recent focus on building local capacity and developing partnerships with other countries such as Norway, there has been minimal curriculum reform and research (Namukasa et al., 2010). As a result, the country's school curriculum largely reflects a blend of modern mathematics and the traditional mathematics of the 1970s. Currently, Uganda has a new competency-based curriculum that emphasizes the shift to equipping mathematics learners with the knowledge, skills, attitudes, and values needed both at school and in the various fields of work (Olema et al., 2021). However, such a curriculum calls for intensive research in mathematics education, basically at the secondary level, because mathematics is performed poorly at the secondary level (Wambi et al., 2024).

The above five components are useful in the implementation of cross-cutting issues reflected in Uganda's lower secondary school mathematics curriculum. Cross-cutting issues are defined in the lower secondary mathematics curriculum as 'issues that develop learners' understanding of the connections between the subjects and the complexities of life' (NCDC, 2019, p. 9). The cross-cutting issues identified in the mathematics curriculum include environmental awareness (links to SDG13: Climate action), health awareness (SDG3: Good health and well-being), life skills (SDG10: reduced inequality, SDG17: Partnership to achieve a goal, SDG5: Gender inequality, SDG4: Quality education), mixed abilities and innovations (SDG10: reduced inequality, SDG17: Partnership to achieve a goal), social-economic challenges (SDG1: no poverty), citizenship, and patriotism (SDG17: Partnership to achieve a goal, SDG16: peace and Justice) (NCDC, 2019).

Similarly, the harmonised curriculum structures and framework for the East African Community draft identified cross cutting issues as both regional and national, and identified some of the cross cutting issues that included: child labour and child rights, HIV/AIDs, environmental conservation and preservation, Disaster risk reduction, Integrity and anti-corruption, Gender responsiveness, Drugs and substance

abuse, Financial literacy and Entrepreneurship (EAC Secretariat, 2014). It should be noted, however, that not all 17 SDGs and mathematics topics can easily be adopted in learning mathematics for sustainability (Domínguez-González & Delgado-Martín, 2022).

The Uganda secondary school mathematics curriculum further identifies five generic skills: critical thinking and problem-solving, creativity and innovation, communication, cooperative and self-directed learning, and mathematical computation and ICT proficiency (NCDC, 2019) required for sustainability learning. Critical thinking involves planning and carrying out investigations, sorting and analyzing information, predicting outcomes and making reasonable decisions, and evaluating different solutions. Creativity and innovation consist of using imagination to explore possibilities, working with others to generate ideas, suggesting and developing new solutions, trying out innovative alternatives, looking for patterns, and generalizing. Communication consists of listening attentively and with comprehension, talking confidently and explaining ideas/opinions clearly, reading accurately and fluently, writing and presenting coherently, and using a range of media to communicate ideas. Cooperation and self-directed learning involve working effectively in diverse teams, interacting effectively with others, taking responsibility for one's own learning, working independently with persistence, and managing goals and time. Mathematics computations and ICT proficiency involve using numbers and measuring accurately, interpreting and interrogating mathematical data, using mathematics to justify and support decisions, using technology to create, manipulate, and process information, collaborating, communicating, and refining their work.

2.3. The role of mathematics education in promoting sustainable development

Vintere and Briede (2016) provides three roles of mathematics in the context of sustainable development: math as an approach to life (helps in understanding of the world), math as a technique (used as a tool to describe and solve the problems and make decisions), and math as a model (contains variety of mathematics models) that can be used to plan for resources, and reducing possible consequences. Additionally, Math4SD develops skills acquisition (García-Alonso et al., 2023; Li & Tsai, 2022; Silveira & Petrini, 2017); modifies personal qualities (Kuznetsova et al., 2021), and motivates learners (Lafuente-Lechuga et al., 2020).

García-Alonso et al. (2023) mathematics training builds Systemic Thinking Competence by enabling us to observe the relationships between the variables of the problem or of these with the information offered in the situation posed and how mathematical knowledge is presented as a tool that helps to achieve a global vision of the problem posed. It improves Critical Thinking Competence focusing on students' lifestyles in terms of sustainable development, investigating and creating new questions to position themselves regarding the issue under analysis. Self-Awareness Competence addresses reflection on the problem and how to modify their behavioral habits. Anticipation Competence entails the analysis of future scenarios in the context of the SDGs regarding the possible consequences and actions to be taken. Finally, Integrated Problem-Solving Competence is divided into two CUs, one related to the depth with which the sustainability problem is dealt with, and the other referring to the use of the mathematical tools proposed for searching solutions in the context provided. ESD-integrated mathematics lessons improve students' competencies and problem-solving skills (Silveira & Petrini, 2017) while the critical nature of Mathematics brings awareness and alternative understandings and interpretations of issues (Li & Tsai, 2022), and Math4SD teaching enhances the development of personal qualities (such as truth and beauty, principles about mathematical culture, and methods of cognition) applicable in an individual's world (Kuznetsova et al., 2021; Lafuente-Lechuga et al., 2020).

2.4. Difficulties in teaching Mathematics for Sustainable Development

Inadequate incorporation of ESD aspects in mathematics education in teacher education and continuous professional development programs is the leading cause of poor teachers' integration during curriculum implementation (Li & Tsai, 2022). This is possibly attributed to the role the curriculum plays in implementing Math4SD lessons (Husamah et al., 2022; Ningsih & Juandi, 2019). According to Husamah et al. (2022) and Kim and Pang (2022), curriculum analysis is only possible if teachers' sustainability

competencies are updated to enhance clear translation and implementation of ESD instruction (Santamaría-Cárdaba et al., 2021; Tatto, 2021).

Regarding interdisciplinary teaching, interdisciplinary activities advocated for in teaching Math4SD are difficult to teach (Renert, 2011). According to Staats (2014), mathematics teachers find it hard to teach mathematics by borrowing from other subjects. Similarly, Yaro et al. (2020) found that mathematics teachers' use of other subject knowledge and cross-cutting issues is challenging. The interdisciplinary approach contributes to a bigger understanding and a bigger picture of the world (Kuznetsova et al., 2021). However, the problem associated with the interdisciplinary teaching of mathematics for sustainability requires not only the use of other subjects but also the integration of the social environment and economic issues (Kuznetsova et al., 2021; Salter et al., 2013; Staats, 2014).

Su et al. (2023) identified challenges mathematics teachers face in the course of implementing ESD to include: lack of training and resources, adaptation using the updated content, use pedagogical approaches that promote sustainability teaching, and negative perception where the whole of concept is taken to an additional separate topic.

3. Methodology

3.1. Research design

The study used a qualitative case study research design with an embedded professional development intervention. Qualitative research describes a phenomenon in words instead of numbers or measurements (Krathwohl, 1993, p. 740). This helped to observe lower secondary mathematics teachers' practices and skills learners acquire through SDGs-integrated mathematics lessons, and to present the data in terms of emergent themes descriptively while using different contexts as they emerged from the data (Krathwohl, 1993). Regarding the Math4SD as a target phenomenon, the approach was necessary for exploration and understanding of participants' experiences (Creswell et al., 2006). The study also acknowledges the fact that the results may be due to the Hawthorne effect, characterised by participants' change of behaviour due to an awareness of the study phenomenon at play (Cook, 1967). The teachers received an intervention about the Math4SD phenomenon. In addition, some teachers had received in-service training in the lower secondary school mathematics curriculum content, though not specifically about the phenomenon, but about learner-centred approaches promoted by the curriculum. Data was collected from students and three teachers from three schools during their regular classes, and the observed lessons took place during the teachers' allocated time on the school timetable.

3.2. Data collection

Primary data from students and teachers was collected using focus group discussions, interviews, and lesson observations. 30–45 min focus group discussions enabled teachers and students to discuss their experiences and challenges about Math4SD in a group setting. These discussions concentrated on the concept of cross-cutting issues/SDGs in the lower mathematics secondary curriculum and the ESD domains (social, economic, and environmental). Teachers' focus discussion was administered before the intervention, while students' focus discussions were conducted after Math4SD lessons were administered. The opening questions aimed to build confidence in the respondents, and the proceeding questions explored their experiences. Semi-structured questions, as seen in Appendix A, were developed and piloted to validate the clarity of the questions. Observations were documented daily in a reflection notebook. Teachers' interviews were also conducted at the end of each lesson. The interviews concluded when the researcher felt that mathematics teachers had adequately explained their experiences. A total of six lessons, two lessons implemented by each teacher, and each lesson had a duration of 80 min.

3.3. Samples and sampling technique

The study used three mathematics teachers and students in their classes from three secondary schools in Uganda. The schools were purposively selected. One private and two government schools, and senior

one mathematics teachers from two districts of Kampala and Wakiso. The two districts were chosen for their proximity and for being among the best-performing districts ranked in the national examinations. Lower secondary mathematics teachers were chosen to gain a better understanding of how they make meaning and implement cross-cutting issues (SDGs) integration in Mathematics classes embedded in the curriculum. The teachers were supposed to have at least 1 year of teaching experience, ensuring that they had a basic understanding of the competence-based curriculum to gain their experience and practices. Both male and female mathematics teachers were included in the inclusion criteria. The teachers and their corresponding class sizes included: Teacher 1 with 72 students, Teacher 2 with 65 students, and Teacher 3 with 96 students. Seven to ten students in the two schools participated in the focus group discussions.

3.4. Mathematics for Sustainable Development project intervention

The intervention had two phases. Phase 1 involved three secondary school mathematics teachers who received training in a three-day workshop, taking 6 h a day. The workshop involved awareness of the concept of SDGs and designing SDGs-integrated mathematics tasks. In this study, the supportive role of the researcher was designing supportive structures that are practical for teachers to use (Psillos & Kariotoglou, 2016). The following areas were selected to support the teachers during the workshop:

1. Understanding the concept of SD and ESD concepts, and SDGs.
2. Knowledge about the integration of cross-cutting issues (financial literacy, climate change, etc.) reflected in the lower secondary school mathematics curriculum.
3. Math4SD modelling focusing on the transformational learning level.

Kim and Pang (2022) transformation example of Math4SD (‘*Which drinks should we choose? Investigate how much sugar is in different beverages. Represent the data in a pictogram and share what you felt through the activity*’). Hence, making such mathematics activities meaningful to the learners.

Phase 2 (the second part of the intervention) involved the exchange of Math4SD modelling tasks from the schemed topic of Business mathematics and discussions after teachers’ lesson presentation to improve practice. The study used an internet inquiry approach to exchange teachers’ developed Math4SD modelling tasks for advice through emails, and WhatsApp for communication and tracking of participants’ progress (Hine, 2013).

During the three-day seminar, teachers were actively involved in selecting topics that they deemed appropriate for sustainability teaching. The business mathematics topic was identified from the lower secondary mathematics curriculum textbooks as an appropriate one since it was among the scheduled topics for that observation period.

Table 1 shows one of the teachers’ initial Math4SD developed tasks and the modified task after discussions. In comparison, the modified task contains attributes supporting Math4SD teaching in terms of: students’ skill acquisition, mathematical computation, and relating content to SDGs. For instance, the task prompts learners to: investigate by visiting different land brokers, which enhances the development of students’ skills. The process of getting answers to the task requires communication and collaboration with the land brokers.

Underpinning the Math4SD intervention are two theoretical perspectives that shaped the conceptualisation, decisions, and actions: professional development and the theory of learning levels for sustainability. These two frames are important in establishing an effective Math4SD secondary school teachers’ learning system. According to Darling-Hammond et al. (2017), professional development is characterised by mentoring, and providing an opportunity to model content for enhancing sustainable learning. The mentoring aspect was provided to the teachers through a three-day seminar. The researcher (being a mathematics teacher educator) mentored, guided, and trained the integration of cross-cutting issues/SDGs into mathematics and modelling Math4SD tasks that fit the transformation level.

Table 1. Math4SD modelling task versions: initial and modified task.

Initial Math4SD task	Mr. Bukenya is a blocker of land in Bukerere Parish in the Mukono district. He has been in this business for many years, and many people are wondering how he earns money because his four children go to good schools, he drives a car, takes care of his family well and has bought many plots of land in the same area, yet he joined this area when he was very poor. One day, joseph, a student of S.1 at St. Charles SS, asked Mr. Bukenya how he earns from this business, and he told him that he is given a 'commission' of 10% on every piece of land he sells on behalf of his clients. Joseph got confused because of the word commission since it was his first time hearing it. On average, Mr. Bukenya sells two pieces of land per week Help Joseph understand what a commission is and how a commission is earned If a month has 4 weeks and a year 12 months, how much money does he earn: a week, a month, a year? What advice would you give to Mr. Bukenya on how to conduct himself so that he is trusted by all the people he deals with?
Modified Math4SD task	Mr. Bukenya is a land blocker in the Goma Division in Mukono district. He started this business when he was very poor, but he has now accumulated wealth. One day, Joseph, a student of S.1, asked Mr. Bukenya how he earns from this business, and Bukenya told him that he earns a commission of 10% on each plot of land he sells on behalf of his client. Joseph got confused because he had never heard of the word commission *Task* 1. Visit different land blockers in the Goma Division and determine the land cost with the following measurements: 100 × 50 m, 100 × 100 m, and an acre 2. Help Joseph to understand what a commission is and how it is earned 3. If Mr. Bukenya sells two pieces of land on average in a month, estimate his monthly income according to your findings 4. Which SDGs are being handled according to this scenario 5. Give reasons why the land of the same size in different areas has different prices

Table 2. Indicators of Math4SD modelling responses.

Learning levels	Indicators/responses in the math tasks
Accommodation	Includes cross-cutting issues/SDGs
Reformation	Include a real-life issue, development of skills, and cross-cutting issues/SDGS
Transformation	Include a real-life issue, development of skills, cross-cutting issues/ SDGs, and an aspect with the ability to change students' beliefs and attitudes

3.5. Data analysis and results

Data was analyzed based on available theories and literature that enhance teaching and learning Math4SD and the acquisition of students' skills as a result of Math4SD implementation. The study used a deductive analysis (using pre-existing categories) imposed by theory and literature (Armat et al., 2018). The pre-existing categories under learning levels included accommodation, reformation, and transformation as codes, and their responsiveness to four aspects: skills development, real-life issues, cross-cutting issues/SDGs, and changes in students' beliefs and attitudes as sub-codes. In terms of students' skills acquisition related to SD teaching, the 21st-century skills of collaboration, communication, critical thinking, and creative thinking as learning outcomes for Math4SD teaching (Widiati & Juandi, 2019) were used as pre-existing codes. The indicators used in categorising lower secondary teachers' Math4SD modelling tasks are referred to in Table 2.

The categorisation was based on the number of aspects that the task contained. At the accommodation level, teachers only mention or talk about the SDGs, while at the reformation level they attempt to use real-life issues, embed approaches that enhance skill development, and integrate SDGs in Mathematics teaching. During the transformation level, in addition to the three aspects used in the reformation level, the teacher adds the aspect of change in the students' beliefs and attitudes. The researcher used the pre-existing categories based on the theory of learning levels and literature about 21st-century skills to code the data.

During analysis, data were highlighted, and observation notes were linked to the themes. Different colors linking to the primary thoughts and practices during the Math4SD lessons resulted in the final themes. The MAXQDA program was utilized to group similar codes into similar concepts.

3.6. Ethical considerations

In this study, permission was obtained from Clarke International University's research ethics committee (number 2024-1106) before going to the selected schools. Makerere University (the affiliated institution) allows the use of all accredited IRBs in the country before conducting research, which is why ethical approval was obtained from Clarke International University. After obtaining study approval, the researcher identified the centers and participants based on the inclusion criteria. The participants had to be lower mathematics secondary teachers, with at least one year of teaching experience, specifically teaching the senior one class.

In addition, the teachers had to separately consent that they had fully understood the research benefits, duration, procedures, risks involved, and precautions taken by the research to mitigate these risks and formally consent to participation in the study.

The researcher went through layers of authorization, going from the parents, teachers, and to get students' consent. Parents were sent a sheet with detailed information about the research benefits, duration, procedures, risks involved, and precautions taken by the research to mitigate these risks and formally requested to consent to their children's participation in the study, but the learners can withdraw at any time, even if their parents and teachers had given permission (Bourke & Loveridge, 2014).

All participants were emphatically informed that all raw data, their identity, and that of their school would not be revealed to third parties (Creswell, 2012). Therefore, the pseudonyms (symbols) 1, 2, 3 were used for the names of the schools that made up the study sites, and the teachers are equally referred to as Teacher 1, 2, or 3, while learners' verbatim responses are presented as coming from a learner in school 1, 2, or 3. Withdrawing from the study at any time was assured. Data was collected between August 2024 and December 2024.

4. Results

The section describes the mathematics teachers' practices from the seven Math4SD lessons in three lower secondary schools in Uganda. The section starts with results addressing research question 1: How do lower secondary school mathematics teachers implement SDGs-integrated lessons? Followed by research question 2: What skills do learners achieve through SDGs-integrated mathematics lessons?

4.1. RQ1: Secondary school teachers' practices in SDGs integrated math lessons

The secondary school teachers' practices are presented using observation field notes and students' focus group discussions.

4.1.1. Sustainable Development Goals integration in the mathematics lesson

The teachers started the five to seven-minute lesson introduction sessions by referring to the SDGs. The students read the SDGs on charts displayed on the wall, while in other classes, teachers provided worksheets to students in groups.

The teachers used a similar approach when concluding the lessons. The students related the taught content to the SDGs using the displayed charts or the worksheets containing the SDGs. The math tasks at the end used by the teachers also included a question specifically about SDGs that prompted students to relate the content learnt. Teachers' statements such as: Which SDGs were handled during the lesson? Which SDGs are being handled according to the scenario? Identify the SDGs appropriate to the task above which were commonly used. The outcome of SDGs integrated mathematics lessons is reflected in the following students' responses during focus group discussions on the question about the importance of integrating SDGs in mathematics teaching.

> Learning maths and at the same time using the SDGs, I am benefiting more. I am studying maths, and at the same time, I am learning the problems, hence it's widening my mind to overcome some of the problems.

Table 3. Shows teachers' Math4SD tasks by learning levels.

Math4SD task	Category and attributes
Teacher 3 Carry out research in the school and find out which individuals earn by receiving commissions. Determine whether they earn below the poverty line. The poverty line is where a person earns below 3000 Ugandan shillings daily	*Category: Reformation* *Attributes reflected in the Task* • Skills • Real-life issue • Cross-cutting issue/SDGs
Teacher 1 Mr. Bukenya is a land blocker in Goma Division Mukono district. He started this business when he was very poor but he has now accumulated wealth. One day Joseph a student of senior one asked Mr. Bukenya how he earns from this business. Bukenya told him that he earns a commission of 10% on each plot he sells on behalf of his client. Joseph got confused because he had never heard of the word commission Visit land blockers in Goma division and find out the cost of land with measurements: 100 × 50 m, 100 × 100 m, and an acre. Help Joseph to understand what commission is and how it is earned. If Mr. Bukenya sells two pieces of land on average monthly, estimate his monthly income according to your findings. Which SDGs are being handled according to this scenario? Give reasons why land of the same size in different areas costs differently	*Category: Reformation* *Attributes reflected in the Task* 1. Real-life issue 2. Skills 3. Cross-cutting issue/SDGs
Teacher 1 Imagine your father has been a government worker for 35 years and he has retired at 60 years. He is given UGX 50,000,000 as his retirement benefit and wishes to start up a shop with an initial capital of UGX 6,000,000. He intends to use the remaining money to construct a permanent house in the village. He has no idea how businesses or shops operate since he has spent most of his life in government office. He wants to deal with items such as rice, posho, cassava flour, millet flour, wheat flour, sugar, cooking oil, salt, packaged water, and sodas. As a son or daughter who has been shopping for food and other items at home, make a market survey for your father to find out the prices of the above items and design a budget for the UGX 6,000,000, indicating the buying and selling prices to make profits. Advise your father how he will be able to know whether he is making losses or profits. What good business behaviors should your father always practice to attract many customers?	*Category: Transformation* *Attributes reflected in the Task* 1. Real-life issue 2. Skills 3. Cross-cutting issue/SDGs 4. Change in beliefs and attitudes

It helps us to get ideas on how to conserve the environment, like water on land.

It has promoted gender equality. Because we, the girls, are given the chance to talk. In the past, girls were not given the chance that we are given now.

4.1.2. Secondary school teachers' Mathematics for Sustainable Development modelling tasks

Teachers' Math4SD tasks oscillated more around the reformation level of learning for sustainability. Teachers in the accommodation level attempted to integrate SDGs, and in the reformation level, teachers integrated sustainability ideas into the curriculum that caused change (Sterling, 2004). Table 3 shows categorization of teachers' Math4SD tasks in accordance with the learning levels based on: content (integration of cross-cutting issues/SDGs into Maths learning), attainment of skills (collaboration, critical thinking, communication, creativity, and curiosity), ability to change students' beliefs and attitudes, and relating issues to real-life.

These results show that the component that changes the students' beliefs and attitudes in learning for sustainability was the least used by the teachers. Only one teacher (Teacher 1) in the transformation category seen in Table 3 included a question that prompted a change in the students' beliefs and attitudes. Teachers found modelling tasks with a question statement that attempts to change students' beliefs and attitudes challenging. All the teachers' tasks were modelled based on real-life issues students commonly meet in the communities. This was evident during students' focus group discussions on the question that required students' responses about their experiences with teaching mathematics that integrates SDGs. Some of the students' responses focused on the importance of teachers' use of real-life-based tasks.

It helps me to introduce to real-world problems.

Learning maths and at the same time using the SDGs. I am benefiting more. I am studying maths and at the same time I am learning about community problems, hence it's widening my mind in order to overcome some of the problems.

It helps because I did not know how the size of 100 square meters of land and how much it costs because of math. The land broker measured it with me, now I practically know what it looks like.

It helped me know more about the outside community. We have been studying mathematics without involving the community. It helped me to know that most of the things we do are linked to solving community problems.

I also got the meaning of commission in other contexts, not only in selling land but also in selling milk.

It helps me to carry out calculations when I am shopping.

In the sections below, we describe and analyse how students developed their skills by working with the teachers' Math4SD tasks.

4.2. RQ2: Skills learners attained through SDGs-integrated mathematics lessons

During the Math4SD lesson implementation described in the next sections, the teachers mainly developed the students' collaboration, critical thinking, and creative thinking skills. This question drew on observation field notes and students' focus group discussions.

4.2.1. Collaboration

In all three schools, the mathematics teachers required students to form several study groups of five to eight members. The groups were formed according to students' proximity; hence, rarely did students move from one place to another to form a group. The small class size compared to the big numbers limited students' free movement. Collaboration (teamwork) was portrayed in different ways. The mathematics teachers mostly involved students in group discussions and presentations. Teachers often provided tasks on sheets of paper to the different groups. Enough time was often provided during group discussions. This increased students' engagement during discussion sessions. During class presentations, teachers used group representatives to solve the given tasks as the rest of the class attentively listened. In cases where the other groups had a different approach from the already presented approach, the teacher let the group present it to the class. This strategy was used to compare the alternative approach to the given task, as well as for time management. Table 4 shows the four different approaches student groups presented in Teacher 1's class when defining the profit concept using the buying and selling price, loan, and total money invested.

Students' collaboration was further demonstrated during group presentations. A single task involving several sections was handled by two or three students, such as assisting the presenter in writing on the chalkboard and in computing values using a calculator. The strategy simplified the presenter's work, taking a shorter presentation time as compared to a single-task presenter.

4.2.2. Critical thinking

Students demonstrated critical thinking when responding to the teachers' mathematics open questions, as seen in Table 5 under the profit and loss concept and discount and profit concept. The Mathematics task: The shopkeeper bought a radio at 80,000/= and sold it at 100,000/=. Calculate his profit. The teacher supplemented and enriched the task to enhance students' understanding by linking profit and loss using real objects (such as a radio and a goat). Similarly, the discount and profit concepts were

Table 4. Definitions of the profit concept in group presentations.

Groups in the teacher 3's class	Approaches used for calculating profit
Group 1	Let M be profit: $M + 2{,}000{,}000 = 5{,}000{,}000$ $M = 3{,}000{,}000$
Group 2	Profit = Total money invested – loan Profit = 5,000,000 – 2,000,000 = 3,00,000
Group 3	Profit = Selling price – Buying price Let y be profit: $y + 200{,}000 = 5{,}000{,}000$ $y = 5{,}000{,}000 - 2{,}000{,}000$ $y = 3{,}000{,}000$
Group 4	Profit = Selling price – Buying price Profit = 5,000,000 – 2,000,000 = 3,000,000

Table 5. Teachers' questions and students' critical thinking responses.

Topic	Teacher's probing questions	Students responses
Profit and loss	*Teacher 1*: If, after some time, the radio owner decides to sell the radio. Why can't the radio be sold at a higher price?	'Maybe the batteries in the radio were used up.' 'The radio is having a virus' 'The radio is old, you cannot buy it at a higher price'
	Teacher 1: When I buy a goat at 120,000/=after 2 years, can I make a profit?	'Yes, because it can produce.' 'Yes, it gains weight.' 'Yes, the goat will not be of the same quality, the radio loses value after 2 years'
Discount and profit	*Teacher 1*: Why do sellers during festive seasons give discounts?	'To increase sales,' 'to get more customers' 'There are many traders trading goods during Christmas.' 'To finish their goods in time' 'To attract more customers,' 'to reduce the old stock and get new stock,' 'to attract tourism,' 'to wish customers happy days'
	Teacher 1: How does a seller make a profit while still giving a discount?	'If there are too many customers, the sales slightly increase'

Table 6. Students' advice to sellers on daily earnings.

Students findings	Students justification quote(s)
Below the poverty line case The sale of 50 avocados at 500 UGX earned a commission of 5% An avocado seller earned a daily earning of 1250 UGX (below the poverty line of 3000 UGX)	'When I understood that she earns below the poverty line, I had to offer some advice. To get another job that can give her more money, so that she goes above the poverty line. The second piece of advice was to diversify and sell other items to ensure that she earns more'
Above the poverty line case The sale of 100 glasses of juice at 1000 UGX earned a commission of 200 UGX per glass, earning a daily income of 20,000 UGX (above the poverty line of 3000 UGX)	'I first related the 20,000 UGX by comparing the daily expenses on food, transport, and monthly housing before I could conclude. In this case, juice is good business'

related to the festive season sales for an in-depth understanding beyond mere mathematical computation.

The results show that the students used critical thinking skills by relating and comparing two opposing mathematics concepts, profit and loss, and profit and discount, to real-life contexts.

4.2.3. Creative thinking

Students' creative thinking was reflected during the Teacher 3's lesson. The task required students to research and justify whether the daily earnings of the small-scale sellers of various food items are above or below Uganda's poverty line index of 3000 UGX, as determined by the World Bank. Table 6 shows the students' advice to the sellers in cases where the daily earning was found below or above the poverty line.

The student's justification in the above poverty-line case did not stop at mere figures. It also reflected on the seller's daily expected expenditure before deciding whether the 20,000 UGX daily earnings were good enough, even when the 20,000 UGX was far from the 3000 UGX above the poverty line.

Some students also expressed their creative thinking abilities during focus group discussions by providing their thoughts on Q3. What is your experience with learning math with the integration of SDGs? How did you feel about that?

> It gives you the experience of creating a job. You can even be more creative and innovative in your job.
>
> It has enabled us to learn concepts like commission. It helps you develop an idea, like starting your mobile money business, and start earning money.
>
> In my opinion, it is good because if I am out of school, like in Senior Four, I can start selling water from the Water sewage Company and get, say, 10% commission. I will have a job to help me in curbing poverty.

The students' creative thinking focused on the ability to create jobs as an outcome of the Math4SD teaching.

5. Discussion

The study's results revealed that in reflection of the three domains (social, economic, and environmental) in teaching for sustainable development, the aspect of the environment was the least used. This finding shows that mathematics teachers highly embedded the social and economic domain while designing the Math4SD tasks. This observation is similar to Sund and Gericke (2020) study in Sweden, which found that teachers teaching science studies (teaching biology, chemistry, physics, and mathematics) taught issues of environmental SD dimension less than teachers of social science studies (teaching civics, history, geography, and religion). However, the results may be because sometimes in secondary schools in Sweden, teachers teach 2 to 4 school subjects together. In contrast, Dube and Lubben (2011) study, which involved 16 junior secondary school science teachers teaching integrated science, found the social and economic domain with the least number perceived in the science curriculum. This study did not specify the 16 teachers' respective specific subjects, which makes it difficult to generalise the results to the Mathematics subject as a science.

The interdisciplinary approach, which involves the different subject teachers meeting and teaching together, provides a new perspective for the Ugandan Secondary Science and Mathematics teachers (SESEMAT) In-service training program which has registered improved students' performance in sciences. The program attracts science (mathematics, physics, chemistry, and biology) teachers in Uganda and uses the Activity, Learner-centred approach, Encouragement, and Improvement (ALEI-) and Planning, Implementation, Evaluation and Improvement (PIEI) model (Kariisa et al., 2015). However, teachers are grouped according to their specific subject, which does not favour the interdisciplinary approach to teaching. Adoption of the interdisciplinary strategy may help in the use of all three domains (social, economic, and environmental) with equal weight, and the effect will be great within a short time. For instance, Kariisa et al. (2015) study aimed to find out the perceptions of secondary school mathematics teachers who had attended in-service training under the Secondary Science Mathematics Teachers' programme. The study employed a mixed-methods approach, collecting data through a survey questionnaire and focus group discussions. The study found that most teachers perceive the SESEMAT programme to have a positive impact on their teaching skills. 67.6% of the teachers either agreed or strongly agreed with the item 'SESMAT Programme has helped me improve my level of content knowledge,' while 70.6% of the teachers either agreed or strongly agreed with the item 'I have concretised ALEI principles after attending SESMAT Programme.'

Regarding skills attained by the students, collaboration was observed as the most exercised skill during the Math4SD lessons. Students demonstrated this through consultations with the community (such as land sellers and milk sellers) during the commission concept. Students made consultations with colleagues through group discussions and class presentations in the process of answering the teachers' Math4SD task. This was possibly due to the nature of the mathematics content that linked to real-life issues and the classroom setting that enhanced group discussion. The high engagement of students during the Math4SD lesson showed a shift from the talk and chalk teacher-centredness associated with Ugandan Mathematics teachers (Hiraoka & Nicholas, 2013) to the highly needed student-centred approach. It should also be noted that the Uganda lower secondary school Competence-based curriculum (CBC), which was rolled out in 2020, may also have contributed to high student collaboration. The CBC promotes learner-centered pedagogy and the development of students' communication and collaboration skills, though teachers still have challenges in implementing it (Tumuheise et al., 2023). However, students' collaboration is affected due to large class size and inadequate resources associated with Ugandan Mathematics classes (Sikoyo, 2010). According to Altinyelken (2010), the majority of the classes have large groups of more than six students during Ugandan lesson sessions.

The role of collaboration competence is further demonstrated by García-Alonso et al. (2023) in their study on the sustainability competencies of prospective mathematics teachers. Systematic thinking competence helps to achieve a global vision of the problem, critical thinking helps students to reflect on sustainable development issues, and self-awareness helps in reflecting on a problem and modification of students' behavior habits, and anticipation competence helps analyse future scenarios in the context of SDGs. This implies that the different competences are coordinated through the collaboration

Table 7. Kim and Pang (2022) Math4SD tasks in the environmental domain.

Topics	Tasks	Objective
Percentage	*Task 1* Check the reuse of bottles. Calculate the increase in empty bottle deposits and find the rate of reuse of empty bottles	Commit to reusing bottles to protect the environment
Statistics	*Task 2* Calculate the percentages of forest decline by looking at the areas of forest in 2000 and 2005 in various regions. Forecast the 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
	Task 3 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	Commit to using water carefully

competence. The teachers' pedagogical approach enhances collaboration in teaching for sustainability. In our study, teachers mostly used case study projects/field trips and discussions. Only one teacher used the role-play method. These approaches highly engaged students. This was possibly due to the project-based learning pedagogy intervention that the teachers received in a three-day workshop training before lesson implementation.

5.1. Limitation

The study was limited to only three Mathematics teachers and their students at the lower ordinary secondary school level in Uganda. Hence, the findings may be interpreted to be unique to the three schools (research sites) or the teachers and their students and, therefore, of limited generalizability. However, the discussion of findings has shown that they are in line with multiple findings from other parts of the world – Asia and Europe, and therefore offer invaluable insights into the experiences of teachers and students in Math4SD teaching.

The study is also limited to business mathematics-related topics that the teachers used during the Math4SD teaching. The NCDC (2019) lower secondary school mathematics curriculum provides non-business mathematics-related topics of fractions, percentages, decimals, and data collection and presentation that can be used in teaching Math4SD in the environmental domain. Kim and Pang (2022) have used percentages and statistics in teaching Math4SD in the environmental domain, as shown in Table 7. These tasks provide an opportunity for lower secondary school mathematics teachers in Uganda to integrate Mathematics teaching within the environmental domain.

Finally, the six hours a day for the three-day workshop was possibly little time for the teachers to attain all the knowledge required to implement the Math4SD concept. Thus, more time on the training should possibly be arranged for future studies.

6. Conclusion

The purpose of the study was to explore Ugandan mathematics secondary school teachers' Math4SD instructional practices. Teachers mostly focused on the social and economic domains while integrating SDGs in Mathematics teaching. The Collaboration skill was used as a baseline, the teachers used this as an entry in the development of other skills (critical thinking, communication, and creativity) required in teaching for sustainability. Theoretically, the study found the teachers' practices in terms of modelling Math4SD tasks under the transformation level challenging. According to the study findings, teachers' Math4SD tasks being involved in the social and economic SD domains was possibly due to the nature of the topic used in the study.

By exploring Teachers' classroom instructional practices during the implementation of Math4SD at the lower secondary school level, the study contributes valuable insights to policy and practitioners who advocate for curriculum alignment to sustainability teaching. For instance, the EAC Secretariat (2014) and NCDC (2019) identified competencies of communication, mathematics competence, personal and

social competencies, learning to learn, ICT, scientific and technological skills, creative thinking, critical thinking, and cultural awareness as required competencies to be developed in the learners during the teaching -learning process. The NCDC further advocates for the integration of cross-cutting issues (SDGs) into the lower secondary school mathematics curriculum. The cross-cutting issues identified included: environmental awareness, health awareness, life skills, mixed abilities and innovation, social-economic challenges, citizenship, and patriotism. The NDP IV second objective: 'Enhance human capital development along the entire life cycle' (National Planning Authority, 2025, p. 58); and the Uganda Vision 2040 identified the skills gap as a key area that hinders development (National Planning Authority, 2014). All these identify the skills and content required for training the Uganda human resource to produce a sustainable working force for a country's development. School leaders should invest in continuous professional development in sustainability teaching, emphasizing promotion of Math4SD modelling under the transformation level and training of teachers in learner-centred pedagogies such as PjBL.

Finally, the study used the theory of learning levels of accommodation, reformation, and transformation in categorisation of lower secondary school teachers' Math4SD modelling tasks. The theory is useful in helping content developers design Math4SD tasks needed at the transformation level, the highest level of learning. This, in turn, can be used in the assessment of Math4SD tasks according to the learning levels.

Acknowledgments

Many thanks to the team behind the Mathematics for Sustainable Development (MATH4SDG) project.

Author contributions

Ismael Gaanya: Conceptualization, methodology, investigation, analysis, and drafting the work. Marjorie Sarah K. Batiibwe: Conceptualisation, reviewed the content, helped in analyzing the data, and approved the final work. Bettina Dahl: Conceptualisation, reviewed the content, helped in analyzing the data, and approved the final work. All authors contributed to the manuscript revision, read and approved the submitted version.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The research leading to these results has been developed for the project supporting Mathematics for Sustainable Development. This work is funded by the Norwegian Agency for Development Cooperation (NORAD), under the Norwegian Program for Capacity Development in Higher Education and Research for Development (NORHED II) Program ID 68105, with the title Mathematics for Sustainable Development (MATH4SDG). The project is based in Norway, working in conjunction with Makerere University, University of Dar es Salaam, Tanzania, and the University of Bergen. The funders had no role in the design of the study, in the collection, analysis, or interpretation of data, in the writing of this manuscript, or in the decision to publish the results.

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Data availability statement

No datasets can be shared due to privacy concerns.

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