

Mathematics as a driver for sustainable development: Pre-service teachers' perspectives on awareness, challenges, and implications for teacher training

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Abstract: Despite mathematics being multidisciplinary, sustainability and mathematics education are largely under-researched and in an infant stage. In the Namibian context, previous research has investigated in-service teachers' perceptions of education for sustainable development and teaching practices. Little is known about pre-service teachers' perspectives on mathematics for sustainable development in terms of awareness, challenges, and how pedagogical modules can be enhanced to develop students' pedagogical knowledge to integrate sustainability concepts in mathematics. The study uses a qualitative approach with an exploratory case study design. Eight third-year pre-service Mathematics teachers were conveniently sampled and completed an open-ended questionnaire. The researcher, informed by the Representations, Educational approach, Didactic tools, and Skills model, conducted a content analysis of participants' awareness, challenges, and implications for training Mathematics teachers. In terms of awareness, the findings revealed that most of the pre-service teachers appear aware and knowledgeable of the role of mathematics in driving education for

sustainable development. The study also found that the major challenges in incorporating ESD in the mathematics teaching and learning process are didactic tools and skills. Based on the study findings, teacher educators should develop student teachers' pedagogical ESD knowledge to be able to link Mathematics to appropriate SD themes, design learning tasks and materials, and present lessons that incorporate SD. The findings of the study provide direction on components to be considered to enhance pedagogical modules for pre-service teachers. This study is limited to a case study of the chosen pre-service teachers and campus and thus cannot be extrapolated to a broader population.

Keywords: Mathematics, pre-service teachers, sustainable development, teachers' awareness, teachers' perspectives.

1. Introduction

A skilled population is imperative for long-term economic advancement and the achievement of sustainable development goals (SDGs). The provision of quality education, which includes Education for Sustainable Development (ESD), plays a crucial role in realising all other SDGs, as it is considered a critical factor in their implementation (Kuznetsova et al., 2021; Su et al., 2023). The concept of sustainable development, as outlined in the United Nations' Sustainable Development Goals (SDGs), highlights the necessity of balancing the economic, social, and environmental aspects of human progress (United Nations Educational Scientific and Cultural Organization (UNESCO), 2017). ESD encompasses various components, including raising awareness, fostering both local and global perspectives, promoting responsibility, facilitating adaptability, encouraging active participation, fostering lifelong learning, nurturing critical thinking, adopting a systemic approach and comprehending complexity, enhancing decision-making abilities, engaging in interdisciplinary problem-solving, and satisfying present needs without compromising the welfare of future generations (UNESCO, 2012).

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Consequently, all United Nations member states, including Namibia, which has ratified this agreement, are required to "Ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including through Education for Sustainable Development (ESD)" (Target 4.7). The question of whether education truly benefits individuals' lives or contributes to the preservation of the planet is an ongoing global concern (UNESCO, 2018). However, the components of ESD are ingrained within the subject curricula of schools (Ministry of Education, Arts and Culture, 2017) as cross-curricular considerations. The absence of explicit sustainability components in school curricula places pressure on teacher educators to equip future teachers with the necessary pedagogical skills to effectively integrate ESD into various subjects.

Mathematics, a subject that is compulsory in many countries' school curricula, functions as a gateway to various fields of science. It provides a foundation for problem-solving, critical thinking, and analytical skills, which are essential in addressing sustainability issues (Kuznetsova et al., 2021; Kuznetsova & Matytcina, 2018; Naidoo & Reddy, 2023). Consequently, a solid grasp of mathematical knowledge and skills is crucial in the pursuit and achievement of Education for Sustainable Development (Widiati & Juandi, 2019; Yasukawa, 2019). As such, mathematics teachers are uniquely positioned to contribute to sustainable development by equipping learners with problem-solving abilities, critical thinking skills, and quantitative reasoning necessary for tackling complex sustainability challenges. However, despite the interdisciplinary nature of mathematics, there is a lack of connection between sustainability and mathematics in the existing research literature (Zulu & Sanjigadu, 2024), making the integration of Education for Sustainable Development during teaching a challenging task. Scholars such as Li and Tsai (2022) have suggested that research in this area has only scratched the surface of the fundamental questions concerning mathematics teaching and learning in relation to Education for Sustainable Development. In addition, a study by Su et al. (2023) concluded that the integration of Education for Sustainable Development concepts in mathematics teaching and learning is still in the early stages of development, particularly in terms of learning content, pedagogy, and the learning environment. Therefore, continuous investigation, particularly in the area of teacher training, is needed.

Similarly, Kuznetsova et al. (2021) expressed that:

At the present stage, a fundamental problem in education is the search for means and methods to integrate sustainable development goals into educational programs and individual disciplines. Initially, sustainable development was understood as a balance between economic growth and environmental protection, and sustainable development education was considered as environmental education. Therefore, there is experience in including sustainable development ideas in teaching disciplines such as biology, chemistry, and life safety. However, for most educational modules, such traditions do not exist. The lack of experience in integrating sustainable development ideas into everyday teaching practice is a challenge for many academic disciplines, including mathematics teachers. (p.2).

These arguments suggest that mathematics teacher educators should have a thorough understanding of the knowledge and skills that teachers need to acquire in order to incorporate sustainable development aspects into all areas of the school curriculum. Li and Tsai (2022, p. 2539) agree with this perspective and argue that mathematics educators have often been asked, "What does math have to do with ESD?" as it is still unclear what is required of teachers in terms of aligning their practice with ESD in the classroom. Therefore, researchers in mathematics education should revisit the integration of ESD in mathematics education and conceptualise how and where efforts should be focused to enhance the integration of ESD aspects in the teaching of mathematics (Kuznetsova & Matytcina, 2018; Li & Tsai, 2022). Consequently, ESD should be included in the training of pre-service teachers across all academic areas in order to successfully integrate sustainability themes. Moreover,

institutional policies play a crucial role in promoting and supporting educators in incorporating the SDGs into their curriculum by providing the necessary tools and explicit instructions.

At the national level, various initiatives have been undertaken, such as documentation and advocacy, to ensure that all students acquire the knowledge and skills necessary to promote sustainable development through their study of school subjects (Ministry of Education, Arts and Culture, 2017). However, in curriculum documents, sustainability ideas are often found only in introductory sections, as part of the aims and rationale, without any links to learning content or teaching guidelines (National Institute for Educational Development (NIED), 2018, 2020). Teachers are given autonomy to make appropriate pedagogical decisions in terms of assessment tasks, learning content, and teaching methodology. The implication of this is that teacher training institutions, which have the responsibility of training teachers, need to provide teachers with the capacity to integrate interdisciplinary mathematical problems that are necessary to drive ESD.

Notably, teacher training institutions at both global and national levels have widely adopted ESD in their teacher training programs (Fischer et al., 2022; University of Namibia (UNAM), 2023). In this study, a particular institution of higher learning has implemented a mandatory core module focused on education for sustainable development, targeting all aspiring teachers. It should be noted that this module is offered independently and is not integrated within pedagogical modules that specifically address subject-specific pedagogical skills. This separation has implications for the professional development of teachers. Furthermore, during the third year of teacher training, pre-service teachers engage in an in-depth exploration of subject-specific pedagogical skills. This year represents a critical juncture in their teacher training journey, as by this stage, the students have already acquired foundational knowledge and practical experiences through coursework and field placements. At the university under consideration in this study, third-year pre-service teachers undertake a year-long module on subject-specific teaching methods, which positions them on the threshold of their teaching careers, leading up to their final teaching practicum.

Given these circumstances, it is crucial to investigate the perspectives of pre-service teachers regarding their awareness of ESD, the challenges they face, and the implications for their teacher training. The findings of such an investigation contribute significantly to the understanding of the areas in which pre-service mathematics teachers may lack knowledge and face challenges. Moreover, these findings can inform the enhancement of pedagogical modules for pre-service mathematics teachers, equipping them with the necessary pedagogical skills for effectively integrating ESD into the mathematics curriculum. Furthermore, the study's findings also serve as a valuable resource within the field of mathematics education and ESD in Namibia. Ultimately, this research endeavor contributes to the broader goal of ensuring quality education (SDG 4) for both pre-service teachers and mathematics learners.

1.1 Problem statement

There is a lack of integration of sustainable development concepts during the teaching and learning of mathematical concepts in Namibian secondary schools. The researcher observed a lack of Sustainable Development (SD) integration in the secondary phase mathematics teaching, with little to no reflection of such in the lesson plans of pre-service teachers during their teaching practicum. These observations were made over a five-year period in three regions of the country. Additionally, nothing is documented on pre-service teachers' perspectives on Mathematics Education for Sustainable Development (MESD), including (a) awareness of the role of mathematics in driving SD, (b) challenges in integrating SD concepts during the mathematics teaching and learning process, and (c) implications for mathematics teacher training. Moreover, in Namibia, research on sustainable development primarily focuses on primary education and/or in-service teachers' perceptions and teaching practices (Anyolo et al., 2018), or generally on other aspects of ESD (Kasanda, 2009; Tshiningayamwe, 2017). Regarding higher education, barriers to the implementation of Education

for Sustainable Development in Namibia's Higher Education Institutions have been investigated (Kanyimba et al., 2014). The findings of the study, therefore, aim to provide insights into how pedagogical modules for Mathematics pre-service teachers can be enhanced to equip them with the necessary skills to promote the integration of sustainable development concepts in the teaching of mathematics.

1.2 Research questions

The study sought to answer the following research questions:

- What are the third-year pre-service Mathematics teachers' perspectives on the role of Mathematics in driving Education for sustainable development (ESD)?
- What are the third-year pre-service Mathematics teachers' perspectives on possible challenges in incorporating sustainable development concepts in Mathematics teaching and learning process?
- How can pedagogical modules for third-year pre-service Mathematics teachers be enhanced to develop the pedagogical skills necessary for ESD integration?

The paper, therefore, begins with a discussion of the literature, including the analytical framework, the Representations, the Educational approach, and Didactic tools and Skills (REDOC) model (Diemer et al., 2019; Khushik, 2021). The methodology used is discussed later, followed by the findings and conclusions of the study.

2. Literature Review

The literature section presents a brief overview of the literature on mathematics for sustainable development and pedagogical strategies for advancing ESD in mathematics pedagogical modules.

2.1 Mathematics education for sustainable development: Description and challenges

Several studies have contributed to our understanding of mathematics education for sustainable development (MESD). For example, Li & Tsai (2022) described MESD as a way of thinking about the world that results from changing understanding and use of mathematics. Meanwhile, Ernest (2020) argued that MESD goes beyond the confines of conventional mathematical philosophy and considers the ability of mathematical applications to guide both human lives and the social world. Therefore, it is important for pre-service teachers to be aware and knowledgeable about the conceptual and practical components of MESD. Additionally, MESD seeks to make mathematics learning more meaningful, useful, and genuine while also promoting the development of 21st-century competencies such as critical thinking, creativity, communication, and collaboration (Widiati & Juandi, 2019; Yuniarti et al., 2019).

MESD demands approaches to teaching, learning, and assessment that promote visionary open-mindedness, responsible citizenship, critical thinking, decision-making, and interdisciplinary problem-solving. Thus, the use of innovative pedagogical approaches is necessary for MESD. These approaches may include problem-based learning, cooperative learning, and the use of digital technology and educational robots to facilitate the development of sustainability-related competencies (Naidoo & Reddy, 2023; Semiz & Baykal, 2020). MESD can be developed through the integration of real-world issues such as resource management, environmental pollution, and climate change and their relationship to mathematics education (Naidoo & Reddy, 2023). Therefore, in order to raise awareness among pre-service teachers, it is crucial to highlight the broader implications of mathematics education beyond traditional boundaries. As argued by Yasukawa (2019), MESD demands that teachers undergo a 'perspective transformation' that involves critical reflection on one's worldviews and taking action to reformulate these views. Thus, teacher educators should focus on building critical reflection abilities to facilitate this shift. Similarly, Kuznetsova and Matytcina (2018) argued that integration should be based on a multidimensional approach to learning, involving the unity of social, psychological, and educational aspects. Therefore, there is no definitive answer to the

question of how to integrate ideas of sustainable development in mathematics teaching in schools and universities (Kuznetsova & Matytcina, 2018).

Generally, educators face challenges due to the complexity of ESD. In a study by Semiz and Baykal (2020), middle school pre-service Mathematics teachers were investigated to determine their opinions on incorporating sustainability into teaching. The majority of the pre-service mathematics teachers were unable to describe multiple aspects of sustainability. These findings suggest a lack of awareness of sustainability concepts among pre-service mathematics teachers, which in turn makes it difficult to integrate sustainability concepts into mathematics teaching.

In another study by Mohd et al. (2024), the challenges of ESD experienced by school leaders in Malaysian schools were explored. The study used a qualitative approach with a single-case study design, interviewing and analysing eight school leaders involved in the Johor Sustainable Education Action Plan (JSEAP). Through thematic analysis, the study identified challenges and causes associated with the implementation of ESD. The study revealed that ESD challenges were perceived at three levels: the standardised curriculum (systemic), resistance to change (organisation), and awareness and readiness (individual). While the participants in this study were school leaders, their findings contribute to a better understanding of the challenges associated with MESD.

Similarly, in a commentary on barriers to ESD based on the reflection of a science teacher, Parry and Metzger (2023) reported inadequate professional learning opportunities for future and practising educators. They argue for a top-down approach that connects Education for Sustainable Development policy to teachers' needs and classroom experiences.

The literature surveyed indicates the importance of teacher educators ensuring that pre-service teachers have a strong understanding of MESD (Ernest, 2020; Li & Tsai, 2022). Additionally, it emphasises the need to incorporate 21st-century competencies such as critical thinking, creativity, communication, and collaboration into the curriculum of pre-service teachers to adequately prepare them (Widiati & Juandi, 2019; Yuniarti et al., 2019). Yasukawa (2019) highlights the necessity for a "perspective transformation" to raise awareness among pre-service teachers about the broader implications of mathematics education beyond subject knowledge. This transformation necessitates the focus on developing critical reflection skills in training programs. The lack of awareness and pedagogical skills to make interdisciplinary connections and integrate sustainable development concepts with mathematics poses challenges for pre-service teachers (Kuznetsova & Matytcina, 2018; Naidoo & Reddy, 2023; Semiz & Baykal, 2020). Therefore, teacher educators must develop teachers based on both ESD policies and their individual needs and classroom experiences (Parry & Metzger, 2023). However, it should be noted that Parry & Metzger (2023) and Mohd et al. (2024) conducted their studies on in-service educators, not specifically on mathematics education, creating a research gap that this study aims to fill. The study seeks to contribute to the literature on MESD by exploring the awareness of sustainable development concepts among pre-service mathematics teachers and the specific challenges they may encounter when incorporating sustainability concepts into the mathematics teaching and learning process.

The study also examines pedagogical approaches for integrating SD in mathematics that teacher educators should impart to pre-service mathematics teachers during their training. The subsequent section discusses the literature on pedagogical strategies that teacher educators can utilise to promote MESD in the training of pre-service mathematics teachers.

2.2 Mathematics education for sustainable development: Pedagogical strategies

Pedagogical approaches drive the teaching and learning processes. ESD is heavily reliant on capacity building and training of teachers who will deliver the subject content and use their own knowledge, values, and skills to promote sustainability at the classroom level (Ferguson et al., 2022). Therefore, skilled and dedicated teacher educators who are driven to be change agents are essential for the

success of teacher education in SD; as such, they can be indicators of the success and failures of an education system for sustainable development (Frisk & Larson, 2011; Yuniarti et al., 2019). In a systematic review on sustainable development education for training and service teachers teaching mathematics, Su et al. (2023) suggest that teacher educators should develop pre-service teachers' content knowledge and pedagogical strategies by comprehensively developing their understanding of the relationship between the environment and Mathematics, as well as Mathematics and other disciplines. They argue that this would enable teachers to incorporate social, cultural, and environmental aspects into the teaching process, promote autonomous learning, and empower students to become agents of social and cultural change. In addition, in their conclusion, they argue for the incorporation of content objectives and assessment criteria that specifically address and guide aspects of sustainability in the field of Mathematics education. Furthermore, this might ease the difficulties teachers may face during practice (Kuznetsova et al., 2021).

Additionally, Helliwell and Ng (2022) in an action research study based on two mathematics teacher educators in the United Kingdom and Hong Kong, explored how our prospective mathematics teachers can be supported in becoming mathematics teachers for sustainable futures by innovating the mathematics teacher education curricula. The duo argue that teacher educators should afford pre-service teachers various opportunities and tasks during teacher training to identify and model aspects of Mathematics teaching that are consistent with ESD and continuously reflect on pedagogical practices against ESD. They (Helliwell & Ng, 2022) believe this would better place teacher educators at the pinnacle to support and develop teaching practices needed for sustainable futures. Ningsih and Juandi (2019) concur that to instil ESD in teaching and learning processes, educators must do curriculum analysis through the lens of ESD components of sociocultural, economic, and environmental challenges; this should be reflected in lesson planning and presentation, assessment, and teaching materials (Ningsih & Juandi, 2019).

Additionally, the infusion approach to teaching with an ESD focus is another pedagogical approach that teacher educators can apply to address ESD more meaningfully. The approach has been used in various parts of the world (Cambers et al., 2008; Ferguson et al., 2022). The approach involves integrating sustainable development concepts into the existing curriculum, whereby teacher educators plan to infuse ESD into the subject area, identify objectives for ESD, match curriculum objectives with ESD goals, and implement teaching strategies with a clear ESD focus. Highlighting the significance of the infusion of ESD into modules to enhance students' knowledge and awareness of SD and ESD, Ferguson et al. (2022) conducted a study on teacher educators within a higher education institution in Jamaica who infused ESD in their module delivery. Data were collected from approximately 140 of their students pre- and post-intervention to ascertain whether individuals' awareness and knowledge of SD and ESD had changed because of the infusion process. Preliminary findings indicate that students' understanding of SD broadened after the modules, with most students believing that SD involves social, economic, and environmental improvements that do not come at the expense of our natural resources. Additionally, students' thoughts about ESD shifted, with students highlighting aspects of the interdisciplinary nature of ESD and ESD as involving equitable, inclusive education.

The literature reviewed provides an overview to discuss and benchmark pedagogical strategies for advancing SD in Mathematics education, as pedagogical strategies taught by teacher educators are implemented by prospective teachers in schools and are therefore, similar. Notably, most studies reviewed and conducted by Su et al. (2023) as well as the study by Helliwell and Ng (2022), are based and led by authors from European countries, Asia, and America, none from Africa. This suggests the need for African scholars to drive research on education for sustainable development in mathematics teacher education. Moreover, some of the studies are linked to high school teachers, such as Ningsih and Juandi (2019). Furthermore, the literature reviewed was mostly conducted in other subject areas, not mathematics. This creates a research gap in terms of appropriate pedagogical approaches

applicable to mathematics teacher education. In the next section, the conceptual framework of this study is discussed.

2.3 Conceptual framework

The study adapted the Représentations, Démarches, Outils, compétences (REDOC) model developed by the Observatory of Development Representations Sustainable (OR2D) (Figure 1) (Diemer et al., 2019; Khushik, 2021). The model was designed based on recommendations for implementing education for sustainable development in education systems (Khushik, 2021). It is also used as a framework in a study on Education for sustainable development in African countries by Diemer (2015). The educational model, REDOC, is used as an analytical tool to structure the representations of pre-service Mathematics teacher participants regarding (a) representations, (b) pedagogical issues, (c) didactical tools, and (d) skills, as well as implications for training Mathematics teachers. The tenets of the REDOC model (Figure 1) are operationalised in the study as follows: representations refer to the participants' awareness of sustainable development and the role of Mathematics in driving it, the skills tenet is used to interpret skill gaps and areas where pre-service teachers believe they need improvement through teacher training. Furthermore, the pedagogical tenet is used to interpret and discuss teaching strategies that teacher educators can employ during teacher training. Lastly, didactical tools are interpreted as encompassing curriculum materials and teaching and learning resources necessary for integrating sustainable development themes in mathematics education.

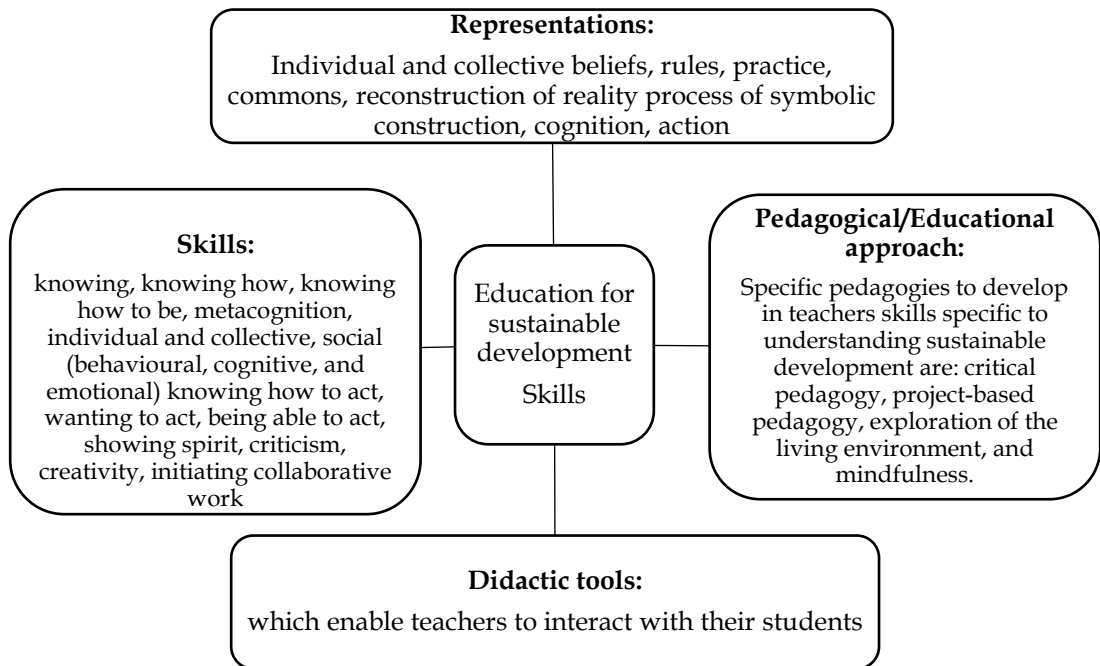


Figure 1: REDOC model adapted from Diemer et al. (2019)

3. Methodology

The study utilised a qualitative exploratory case study research design by administering an online open-ended questionnaire to third-year full-time mode pre-service Mathematics teachers who were registered for the pedagogical module in Mathematics. The exploratory case study design was chosen for this study because it allows flexibility in choosing the most appropriate method of data collection and also allows for generalisations based on analysis (Priya, 2021). A qualitative case study enables researchers to explore the perspectives of pre-service mathematics teachers on awareness, challenges, and suggestions for pedagogical approaches in mathematics education for teacher educators (Denzin

& Lincoln, 2018). The researcher ensured the trustworthiness of the data by constantly reflecting on their biography, social position, values, biases, and preconceptions and consciously setting them aside during the research and data analysis process (Priya, 2021).

3.1 Context and participants

The participants in this study were third-year secondary school pre-service teachers at a public university in Namibia. The teacher education program in which they were enrolled is a four-year-long program that aims to produce teachers who teach Grades 8 to 12. The program includes primarily content modules (e.g., subject modules taken from the Faculty of Agriculture, Engineering & Natural Sciences) and educational sciences modules taken from the Department of Applied Educational Sciences in the School of Education. In the third year, pre-service teachers complete a module on subject-specific teaching methods, which puts them on the cusp of their teaching career and prepares them for their final teaching practicum. A university of interest in this study has introduced a mandatory module on ESD for aspiring teachers, but the participants in this study only gained knowledge of sustainable development through the modules covered in their teacher education training. Convenience sampling was used to select eight participants out of thirty-three students, based on their registration for the Teaching Methods of Mathematics module in the full-time mode, as they were easily accessible for data collection. Full-time students also had more time to participate in additional activities, such as this study, compared to part-time students who are also engaged in employment activities. Six out of the eight participants completed the online open-ended questionnaire. The participants were given pseudonyms (e.g., ST1 for Student Teacher 1, ST2 for Student Teacher 2) to protect their identities.

3.2 Instrument and data collection

The data was collected using an open-ended questionnaire adapted from Semiz and Baykal (2020). In the open-ended questionnaire, participants answered questions based on the research questions of the study, after they consented to participate. Data collection took three weeks, allowing participants sufficient time and convenience to complete the open-ended questionnaire. The link to the online open-ended questionnaire was shared with participants on the module's WhatsApp group to ensure students could conveniently access the link. The completion of the online questionnaire took approximately 15 minutes.

3.3 Data analysis

Qualitative data analysis began by first interrogating participants' responses to the open-ended questionnaires. Second, the data was subjected to content analysis. The standard method of content analysis implies "making judgments about the meaning of sections of text by marking them off and assigning a tentative label (code) and definition to describe what the text represented" (Fonteyn et al., 2008, p. 165). Third, common themes and patterns in participants' responses were identified, coded, and categorised to reveal prevalent perspectives on integrating sustainable development in mathematics education. Fourth, the representation, skills, and pedagogical tenets of the REDOC model (Diemer et al., 2019; Khushik, 2021) were used as an analytical framework to categorise participants' responses. Based on the REDOC model, representations were those that describe pre-service teachers' awareness of SD and the role of mathematics in driving SD. The skills tenet is used to interpret skill gaps and areas that pre-service teachers believe need strengthening through teacher training. Furthermore, a pedagogical tenet is used to interpret and discuss teaching strategies that teacher educators can employ during teacher training. Lastly, didactical tools are interpreted to encompass tools such as curriculum materials and teaching and learning resources necessary to integrate sustainable development themes in mathematics education. The trustworthiness of the coding process was achieved through peer review.

3.4 Ethical consideration

The Decentralised Ethics Committees granted ethical clearance for this study at the participating university. Participants were provided with comprehensive informed consent and were asked to consent before they could proceed with completing the online open-ended questionnaire. No coercion or any form of enticement was used to lure participants into participating in this research. Participants had the right to withdraw from the study at any stage if they wished to do so. Withdrawal from the study resulted in no negative repercussions for the participants. Participant coding was used to ensure the confidentiality, privacy, and anonymity of participants.

4. Presentation of Results

This section presents the data. As mentioned in the methodology section, a total of six participants out of eight completed the open-ended questionnaire. The participants were given pseudonyms to protect their identities, with ST1 representing Student Teacher 1, ST2 representing Student Teacher 2, and so forth. The data is presented based on the research questions:

- What are the third-year pre-service Mathematics teachers' perspectives on the role of Mathematics in driving Education for sustainable development MESD?
- What are the third-year pre-service Mathematics teachers' perspectives on possible challenges in incorporating sustainable development concepts in the Mathematics teaching and learning process?
- How can pedagogical modules for third-year pre-service Mathematics teachers be enhanced to develop the pedagogical skills necessary for ESD integration?

4.1 Representation of mathematics in driving education for sustainable development (ESD)

Participants were asked to provide their perspectives on the role of mathematics in driving sustainable development. The responses aim to answer research question one. Research question one aimed to describe how pre-service teachers perceive sustainable development and the role of mathematics in promoting education for sustainable development. Various representations of how mathematics can be incorporated into ESD were noted as follows:

ST1: Exploring sustainability concepts through Mathematics encourages learners to think critically, analyse data, and evaluate the impact of different decisions to foster their ability to make informed choices for a sustainable future.

Complimentary:

ST2: Sustainable development in mathematics helps to use mathematics to solve real-world problems related to sustainability and environmental issues.

ST3: ESD in Mathematics is when teachers develop learners' critical thinking, decision-making, and awareness of the world.

ST5: It is important that students realise that the sustainability of the planet is at stake and that we can solve many problems with the help of the tools provided by mathematics.

However, ST6 discussed the connection between mathematics and everyday life as well as the power of mathematics education to the learners, thus notes:

To take learners from the world of darkness into the world of light. Mathematics is crucial. It is used in everyday life, and mathematical computation is one of the fascinating aspects.

Contrarily, ST4 seemed to be not aware of the concept of sustainable development, as the response lacked the connection to broader sustainability concepts nor mathematics, as explicitly written:

Sustainability in Mathematics means that teachers should be aware of student overload - As a Mathematics teacher, you should avoid overloading students. Although Mathematics becomes easy through practice, teachers should avoid giving learners tasks daily since they have other subjects.

Most (four out of six) of the participants noted that mathematical skills play a critical role in promoting ESD. Notably, participants focused on the importance of cognitive skills gained through mathematics teaching, such as critical thinking, analytical, problem-solving, and decision-making skills. These skills are also emphasised in the Namibian Mathematics curriculum (National Institute for Educational Development (NIED), 2015, 2018, 2020). However, some participants seem to be unaware of the concept of sustainability and the role of mathematical skills in driving sustainable development. Only one participant appears to be unaware of the concept of sustainable development and instead focuses on the context of educational practices, learners' psychological aspects, and the importance of balanced teaching practices.

4.2 Challenges in incorporating ESD in mathematics teaching and learning process

When pre-service teachers were asked about the potential challenges they are likely to face as mathematics teachers in incorporating sustainable development into their teaching, four participants responded to this question, while the other two left it unanswered. The responses aimed to answer research question number two.

ST1 describes challenges in terms of a lack of assessment and pedagogical skills, as well as shortcomings in the present assessment methods, as they fall short of measuring interdisciplinary understanding. Additionally, ST1 noted challenges with the curriculum structure, as it does not align sustainability-related concepts with the existing mathematics curriculum. As ST1 wrote:

ST1: Assessment difficulties: Evaluating students' understanding of sustainability concepts within mathematics assessments may be challenging, especially since the traditional assessment methods don't align well with these topics.

This may entail rethinking present assessment techniques in mathematics and using interdisciplinary pedagogical approaches. The response may also suggest that incorporating sustainable notions into mathematics education necessitates a dual focus, that is, evaluating mathematical abilities and understanding sustainability themes.

Moreover, ST2 noted challenges with appropriate pedagogical skills to integrate sustainable development concepts in mathematics education as follows:

ST2: Lack of experience in integrating sustainable development ideas into everyday teaching practice

In addition, ST3 and ST5 noted challenges related to the learners' motivation, learning style, teaching approach, and classroom management. Thus briefly, noted as follows:

ST3: Learners not coping with the teaching approach being used.

ST5: Learners not willing to learn.

Based on the ST1, ST2, ST3, and ST4 responses, Table 1 summarises the challenges that pre-service teachers envision encountering when incorporating sustainable development concepts into teaching Mathematics. The challenges are grouped and linked to the REDOC model.

Table 1: Codes relating to description and challenges

Responses	Description	Code
ST1: Assessment difficulties: Evaluating students' understanding of sustainability concepts within mathematics assessments may be challenging, especially since the traditional assessment methods don't align well with these topics.	A mismatch between mathematics curriculum and assessment approach	Didactic tools
ST2: Lack of experience in integrating sustainable development ideas into everyday teaching practice	Teaching experience	Skills
ST2: Lack of experience in integrating sustainable development ideas into everyday teaching practice	Knowledge of sustainability concepts	
ST3: Learners not coping with the teaching approach being used.	Learning style	
ST3: Learners not coping with the teaching approach being used.	Pedagogical skills	
ST1: Assessment difficulties: Evaluating students' understanding of sustainability concepts within mathematics assessments may be challenging, especially since the traditional assessment methods don't align well with these topics.	Assessment skills	
ST4: Learners not willing to learn.	Classroom management skills	

Table 1 shows that most of the challenges identified by pre-service teachers are related to skills. This suggests that pre-service teachers perceive skills as crucial in promoting the integration of sustainable development concepts in the teaching and learning of mathematics.

4.3 Implications for the pedagogical module during teacher training

This section focuses on addressing research question number three, which explores how pedagogical modules for third-year pre-service Mathematics teachers can be improved during teacher training to foster sustainable development knowledge in learners through teaching Mathematics. This question is linked to the pedagogical aspects of the REDOC model (refer to Figure 1). Participants were initially asked to assess the extent to which they believe the teacher training modules adequately equip them to integrate sustainable development concepts into their future mathematics classrooms. The majority of participants (four out of six) indicated that the teacher training modules prepared them to promote sustainable development in mathematics teaching. They mentioned that:

ST2: To the most extent.

ST3: I think 80% because I never felt the same way I started as a student, am well convinced, and believe that I can integrate sustainable development, which is positive about Namibian goals, and create a better future for my children [learners].

ST4: Yes

ST6: Yes

However, other participants (two out of six) indicated that they are not well prepared to incorporate sustainable development in future Mathematics teaching. This is so because they think the modules do not have an explicit focus on Education Sustainable Development (ESD) [ST1, ST5].

ST1: *I am not well prepared. Mathematics teachers will benefit from specialised training or professional development programs that focus on sustainable development education. This would help us mathematics teachers to gain the knowledge and skills needed to integrate sustainability topics seamlessly into their mathematics lessons.*

ST5: No

Moreover, participants noted various teaching approaches that can be employed to promote sustainable development in teaching Mathematics. ST2 noted that mathematics teachers are custodians in promoting avenues for collaboration in classrooms through peer engagement and support, which would not have been *possible without them*. ST5 and ST6 penned that teachers should use appropriate classroom management strategies as well as plan teaching resources that would promote ESD skills in the learners. The following excerpt exemplifies the results:

ST5: *They [Mathematics teachers] must provide posters in class for learners to be familiar with mathematical basics.*

ST6: *Mathematics teachers are critical in providing peer engagement and support. Therefore, they should engage learners in group discussions and project strategies when possible.*

When participants were asked about specific teaching strategies that Mathematics teachers can employ to integrate sustainable development into their lessons, they noted a combination of learning activities (ST2, ST3) and teaching approaches (ST6 and ST5). This relates to the pedagogical issues on the REDOC model. Explicitly,

ST2: *Modelling of problems on Mathematics Education for Sustainable Development*

ST3: *Project-based learning: Engage students in project-based learning activities focused on sustainable development.*

Furthermore, ST5 generally stated a learner-centred approach, while ST6 explicitly noted the *discovery method*.

Although not directly related to the question asked, some STs indicated the need for professional development intervention and curriculum expansion. The viewpoints are interpreted as suggestions to expand the Mathematics curriculum to introduce a subject called *Mathematics for sustainable development (MESD)*, and these would require professional development. As ST4 indicates that

Mathematics teachers will benefit from specialised training or professional development programs that focus on sustainable development education. This would help us, Mathematics teachers, gain the knowledge and skills needed to integrate sustainability topics seamlessly into their Mathematics lessons and subjects.

Moreover, participants were asked to write down how pre-service pedagogy modules can better prepare and equip Mathematics teachers with the necessary teaching skills to promote sustainable development in Mathematics. Participants noted that during pedagogy sessions, lectures should *'demonstrate how to incorporate sustainability-related problem-solving tasks and projects into their future classrooms'* (ST1). *They should provide teaching aids that can be used to promote SD concepts in Mathematics lessons* (ST3). Similarly, ST2 noted that pedagogy lecturers should

Demonstrate mathematical problems and tasks to pre-service teachers on (a) how to incorporate sustainability-related problem-solving tasks and projects into their future classrooms. (b) How can we create connections between mathematics as an abstract subject and everyday experiences?

In addition, other STs noted that pre-service trainers should emphasise the importance of mathematics by collaborating with industry experts to influence attitudes and habits and see mathematics as something logical, useful, and worthwhile (ST4 and ST6).

ST4: Recruit a social advisor from a higher education office to give a motivational speech to help develop the mathematical dispositions of students.

Also, ST6 noted that teacher educators should *collaborate with experts and organisations specialising in sustainability to enhance the quality and relevance of mathematics programs.*

In relation to the REDOC model, ST4 and ST6 might imply influencing the tenet of pre-service teachers' representations. Therefore, collaborating with industry experts might influence the attitudes, teaching decisions, and actions of pre-service mathematics teachers towards mathematics for sustainable development.

5. Discussion of Findings

The findings reveal that most of the pre-service mathematics teachers are aware of sustainable development concepts and the role of mathematics in driving ESD. Some participants highlighted the importance of fostering critical thinking, decision-making, and awareness of real-world sustainability issues among learners, as noted by Naidoo and Reddy (2023) and Semiz and Baykal (2020). The findings imply that MESD goes beyond conventional mathematical philosophy and abstract knowledge to the application of mathematics in building human lives and the world (Ernest, 2020; Li & Tsai, 2022). These findings strengthen the need and importance of incorporating sustainability themes into mathematics pedagogy to promote students' understanding of the environment, resource management, and climate change (Kuznetsova et al., 2021; Kuznetsova & Matytcina, 2018), as well as promoting the development of 21st-century skills (Widiati & Juandi, 2019; Yuniarti et al., 2019). The representation of the role of mathematics in driving ESD, as avoiding subject content overload and focusing on learners' motivation and willingness to learn, suggests an unawareness and possible misunderstanding of ESD's scope and implications. The response concurs with the findings by Semiz and Baykal (2020) and highlights the complexity of integrating sustainability into mathematics education, emphasising the need for a comprehensive approach that addresses diverse perspectives (Kuznetsova & Matytcina, 2018; Semiz & Baykal, 2020). Therefore, teacher educators should steer the perspective transformation of pre-service teachers toward MESD (Yasukawa, 2019) to ensure that pre-service teachers are well-versed in what MESD entails (Ernest, 2020; Li & Tsai, 2022) to be able to use mathematics as an avenue to drive ESD.

The challenges in integrating ESD into the mathematics teaching and learning process include a lack of understanding of sustainability concepts, a mismatch between curriculum topics and assessment approaches, and skills-related issues. Moreover, the findings also imply that the major challenges in incorporating ESD in the mathematics teaching and learning process are (a) didactical tools, and (b) skills (Diemer et al., 2019), also referred to as systemic and individual awareness and readiness by Mohd et al. (2024). The challenge of awareness and readiness of an individual falls within the scope of the teacher educator and can be influenced during the pedagogical module. This is to ensure that pre-service teachers are holistically and comprehensively prepared during teacher training (Naidoo & Reddy, 2023; Parry & Metzger, 2023; Semiz & Baykal, 2020).

Moreover, the study reveals differences in perspectives regarding the effectiveness of teacher training modules in preparing pre-service Mathematics teachers to incorporate sustainable development into their future teaching practices. Some participants express confidence in their preparedness, while others feel that the pedagogical modules lack an explicit focus on ESD, highlighting potential gaps in teacher education programs. Further, the findings indicate that during teacher training in pedagogy modules, teacher educators should highlight the importance of incorporating sustainable development concepts in mathematics teaching, engage students in

practical scenarios, and provide teaching aids. The findings agree that the infusion of ESD in teaching heavily relies on capacity building and teacher training. Thus, teachers should be provided with tasks and various opportunities to model and reflect in order to develop pedagogical strategies needed for ESD integration (Ferguson et al., 2022; Frisk & Larson, 2011; Helliwell & Ng, 2022). Furthermore, the study emphasises the role of pedagogy lecturers in demonstrating how to create connections between Mathematics and everyday experiences, echoing the literature's call for a multidimensional approach to training Mathematics students (Kuznetsova & Matytcina, 2018).

Figure 2 models how pedagogical modules for third-year pre-service Mathematics teachers can be enhanced to develop the pedagogical skills necessary for ESD integration during the mathematics teaching and learning process. Figure 2 depicts that teacher educators should create collaboration opportunities between themselves (teacher educators), curriculum experts, and ESD experts to develop appropriate pedagogical skills for ESD in mathematics. The collaboration team should also aim to influence Mathematics teachers' disposition toward the role and significance of the subject in driving ESD agendas. Teacher educators should develop student teachers' pedagogical ESD knowledge to be able to link Mathematics to appropriate SD themes, design learning tasks and materials, and present lessons that incorporate SD. The organisation of components of Figure 2 suggests bi-directional links to propose a holistic approach to enhancing the integration of ESD into the mathematics teaching and learning process. The links between components suggest the possible influence a component has on others. Thus, a change in one component might lead to a change in another, as well as an individual pre-service teacher's ability to infuse ESD in mathematics.

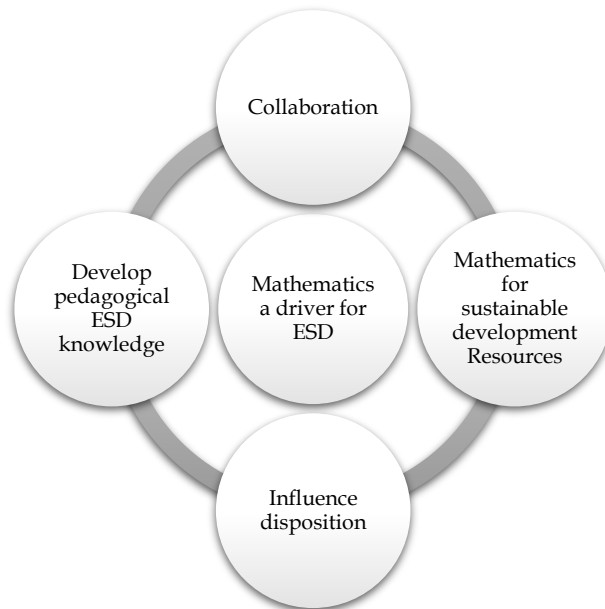


Figure 2: Mathematics as a driver for education for sustainable development

6. Conclusions and Recommendations

As the world grapples with pressing sustainability challenges, the critical role of mathematics teachers in nurturing responsible and globally conscious citizens cannot be underestimated due to the nature of the subject. The researcher argues here that efforts should be directed towards enhancing the integration of ESD aspects in the teaching of mathematics. Based on the findings of the study, it is recommended that a specialised module on mathematics education for sustainable development would enhance the seamless integration of SD concepts in mathematics lessons since the current practice of infusion is challenging. Additionally, the study further recommends that

teacher educators should create collaboration opportunities between themselves (teacher educators), curriculum experts, and ESD experts to develop appropriate pedagogical skills for ESD in mathematics. The collaboration team should also aim to influence mathematics teachers' disposition toward their role and the significance of the subject in driving ESD agendas. Teacher educators should develop student teachers' pedagogical ESD knowledge to be able to link mathematics to SD concepts, design learning tasks and materials, and present lessons that incorporate ESD. The present study concluded with possible components to enhance pedagogical modules during teacher training for pre-service teachers to use mathematics as a driver for Education for Sustainable Development. However, further study should be conducted to develop explicit steps that can be taken to support mathematics teachers in integrating ESD into their teaching practices. Further studies should also be carried out on ESD and mathematics pedagogy to ensure that ESD concepts are integrated throughout the school curriculum. The study contributes to the ongoing discourse on promoting sustainable development through mathematics teaching and teacher education. Moreover, further study should be carried out to propose and develop long-term strategies for sustaining the integration of ESD in mathematics education, as well as directions on continuous professional development, curriculum revisions, and collaborative initiatives that can be maintained over time to ensure lasting impact.

7. Declarations

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Data availability: The data supporting the findings of this research can be obtained upon request from the corresponding author. While the data is included in the article, ethical guidelines obtained for the study prevent its public accessibility in order to uphold confidentiality between the author and participants.

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