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Mathematics Teaching for Sustainable Development: Challenges and Successes

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Abstract: Mathematics teaching for sustainable development is fraught with challenges that hinder meaningful learning and the acquisition of problem-solving skills essential for environmental, economic, and societal responsibility. Therefore, mathematics teaching requires effective skills to apply heuristic strategies for sustainable human development, enabling a learning progression from the fourth to the fifth industrial revolution. Effective instructional practices must focus on including learners' cultural and social realities through democratic dialogue. This research draws from algo-heuristics theory, which highlights a prescription-oriented approach as opposed to process-oriented teaching methods. This qualitative phenomenological study engaged six purposively sampled mathematics teachers, teaching grades 8 to 12, in a focus group interview and classroom observations. The engagement aimed to explore the successes and challenges faced in the mathematics classroom in relation to the attainment of the Mission 2030 sustainable education goals. Findings revealed that mathematics teachers lack sustainable teaching skills, and their practices lean towards prescription-oriented and algorithmic teaching methods, which contribute to impractical and dysfunctional learning environments. Consequently, mathematics teaching does not foster learning that equips students with the sustainable abilities needed to achieve the Mission 2030 sustainable education goals. To minimise these challenges and support teachers in applying process-oriented heuristic teaching methods, teacher empowerment is necessary. In essence, mathematics teachers should be guided in the application of process-oriented teaching strategies that enable them to implement meaningful learning for sustainable development.

Keywords: Algorithm, heuristics, prescription-oriented teaching, problem-solving, process-oriented teaching, sustainable development.

1. Introduction

The guidelines of Mission 2030 for sustainable development are essential for directing teachers to apply relevant strategies in their teaching. Appropriate teaching strategies are necessary to equip learners with Fourth Industrial Revolution (4IR) skills to meet the operational demands of the Fifth Industrial Revolution (5IR). The 4IR skills associated with sustainable development in this study include authentic learning through critical inquiry, which fosters creativity and critical thinking (Masilo, 2024). The author distinguishes between 4IR skills and 5IR skills, noting that the latter encompasses abilities related to knowledge creation for application in problem-solving.

The implication of this study is that teachers require teaching skills that can empower learners with abilities such as critical inquiry, creativity, and critical thinking for sustainable learning. This will enable students to create and produce knowledge in the future and beyond the classroom. Sustainable development calls for development and empowerment through education to solve problems related to the economy, society, and the environment (Naidoo & Reddy, 2023; Schrage & Langlet, 2016). The authors argue that one of the goals of sustainable development is to address societal challenges, including hunger, poverty, clean energy, gender equality, education, and climate change.

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Schools exist within societies where challenges align with the goals that sustainable development seeks to address. To tackle these issues, the sustainable development initiative advocates for collaboration among entities such as the government, businesses, and community members. Education is a valuable asset that produces competitive business experts, government structures, and skilled individuals who can solve daily problems to meet their needs and wants (Naidoo & Reddy, 2023). Therefore, it is essential for every government to develop and provide effective activities and resources for the education system, specifically for teaching and learning. This research focuses on the challenges and successes of sustainable development in the teaching of mathematics within the South African context.

Naidoo and Reddy (2023) state that sustainability in mathematics education incorporates strategies for teaching, learning, and assessing mathematics that focus on environmental responsibility, relevance, and effectiveness. In addition, they emphasise that mathematics teaching, in reference to sustainable development, should support students' development of critical thinking and mathematical problem-solving skills for real life. In relation to sustainable development, the theory of education for human sustainable development adds value to education by supporting learners' well-being through (1) democratic dialogue and (2) inclusion of cultural and social realities in learning (Schrage & Langlet, 2016). Considering the authors' views, this research argues that mathematics teaching has long avoided a democratic dialogue between teachers and learners and has capitalised on the exclusion of learners' social and cultural realities. Therefore, such exclusion indicates that learners' well-being for sustainable learning is a factor requiring teacher attention, given the need for the inculcation of individualised learning experiences aligned with social, cultural, and technological encounters.

Furthermore, this research emphasises that heuristic methods of teaching are critical for the sustainability of mathematics education, instilling in learners the skills needed for the Fourth Industrial Revolution (4IR) in preparation for producing competent individuals skilled in the Fifth Industrial Revolution (5IR). Nokhatbayeva (2020) highlights that heuristic teaching methods are associated with the science of making discoveries (p. 144). The essence of heuristic teaching methods in mathematics relates to the enhancement of student performance, the development of logical thinking skills, and the encouragement of active learning and problem-solving (Rwehabura & Kaponga, 2024). The heuristics pedagogical skills encompass designing skills, constructive skills, organisational skills, and performing skills (Nokhatbayeva, 2020). The author emphasises that designing skills refer to teachers' ability to set learning goals, select appropriate strategies, design lessons, choose suitable heuristic teaching materials, and foresee and provide for difficulties that might hinder heuristic learning. The teachers' constructive skills contribute to the ability to include a variety of forms and methods of teaching, as well as to design relevant heuristic technologies to support learners' heuristic activities. Organisational and performing skills equip teachers to generate learner interest, motivate learners to engage in heuristic activities, and support learners in advancing independent discovery.

Considering the essence of heuristic teaching methods, I emphasise in this research that mathematics teachers should be enlightened to practice facilitation strategies that align with (1) a democratic dialogue supported by learners' experiences of cultural and social imperatives and (2) the development of skills of exploration and discovery in learners. By facilitating discovery and exploration, teachers can equip learners with self-regulated learning skills that foster inquisitive minds and advance critical thinking and creativity for problem-solving. Nonetheless, various circumstances hinder the successful and sustainable teaching of mathematical knowledge and skills, which are essential for equipping learners with the appropriate skills envisioned for the sustainable abilities of the 5IR era. For example, challenges to sustainable mathematics teaching include insufficient professional development, facilitator skills, connections to learning theory, a lack of resources, and inadequate time for collaboration (Mokgwathi et al., 2023; Olteanu, 2018). Despite

these challenges, a paradigm shift is necessary in mathematics teaching, focusing on overcoming obstacles to produce learners who can develop mathematical skills and knowledge for the creation of knowledge as future scientists. Mathematics, as a science, aims for the application of critical thinking, as well as the abilities to analyse, reason, and solve problems in societies increasingly inclined towards the 4IR.

In villages like those in the Tshwane North area, where this study took place, schools are at an advanced stage, with digital resources available for both teachers and learners. For example, schools are equipped with computer labs, classrooms feature interactive whiteboards, and mathematics teachers attend regular professional development workshops. In addition, learners have laptops for their studies. Therefore, this research argues that such resources are appropriate for enabling 21st-century learners to apply self-regulated learning and active learning to explore and discover mathematical realities necessary for sustaining critical thinking, analysis, and reasoning skills. Furthermore, this research noted that, despite the availability of resources and their potential advantages, the teaching strategies currently employed in mathematics are still linked to past eras, where only chalkboards and textbooks are regarded as the primary teaching resources. The teachers' inability to utilise the available resources aligns with findings by Lestari et al. (2024), which indicate that mathematics teachers face challenges such as time constraints and a lack of understanding of sustainable education; thus, the inclusion of sustainable teaching strategies remains limited.

It is critical that the strategies teachers employ to impart mathematical knowledge and expertise also regulate the strategies students use to advance sustainable learning in mathematics. For example, if teaching does not encourage the learning skills of a scientist, learners cannot learn as scientists; therefore, the envisioned mission of sustainable development to advance sustainable learning cannot be achieved. Given this, current mathematics students are not equipped to utilise the resources at their disposal as learning tools to further sustainable learning in alignment with the Fourth Industrial Revolution (4IR). This indicates that preparation for the Fifth Industrial Revolution (5IR) cohort of problem solvers has not yet begun in mathematics teaching. Listeri et al. (2024) highlight the importance of integrating sustainable development principles into the teaching and learning of mathematics to promote learners' sustainable skills. However, teachers in most mathematics classrooms, including those in schools that participated in this research, have not yet begun to apply sustainable development teaching strategies or take advantage of the available resources to (1) engage learners in utilising these resources for meaningful learning; (2) involve learners in ways that allow them to learn and retain knowledge in long-term memory; and (3) support inductive-deductive discovery learning. Therefore, this research sought to identify the challenges in applying sustainable mathematics teaching in the 21st century to equip learners with the sustainable skills needed for the 5IR. This research determined the obstacles that hinder mathematics teachers from empowering learners with the knowledge, skills, and abilities to integrate algorithmic and heuristic knowledge, deducing and retaining knowledge for application in problem-solving towards sustainable development.

2. Literature Implications

The following themes are integrated with literature to interrogate the challenges and successes of mathematics teaching for sustainable development: (1) teaching mathematics through heuristic strategies for sustainable development; (2) the heuristic approach to sustainable problem solving; and (3) heuristics versus algorithm teaching strategies.

2.1 Teaching mathematics through heuristics strategies for sustainable development

Mathematics knowledge contributes significantly to resolving sustainability challenges across various sectors, including industry, education, society, and the economy (Kuznetsova, 2021). At the secondary school level of mathematics learning, teaching for sustainable development should aim to

assist students in understanding the impact of mathematical decisions on their immediate society and the economy (Lestari, 2024). This understanding can enable them to apply relevant decisions in social and economic problem-solving. The authors' perspective on a breakthrough in incorporating sustainable development is that a mathematical culture for learners is created. However, the authors emphasise that the challenges of employing sustainable development in teaching mathematics stem from the complexity of inclusion in the curriculum, as opposed to considering strategies for creating a learning process that integrates educational, psychological, and social aspects.

Therefore, it is essential to incorporate philosophies that align with sustainable development in mathematics teaching and learning. Sustainable development in teaching mathematics can be maintained through heuristic teaching strategies. Heuristic teaching methods include guided inquiry-based learning strategies (Rayner-Canham, 2015). Through inquiry-based facilitation as a heuristic teaching strategy, learners are afforded opportunities to advance their knowledge through research and exploration, developing 21st-century learning skills such as critical thinking and problem-solving (Joseph, 2022; Masilo, 2018; Shanmugavelu et al., 2020). When applying the heuristic strategy in teaching mathematics, a step-by-step approach is essential. This includes (1) starting the delivery of content by orientating learners to the perception and visualisation of mathematical concepts; (2) delivering the functionalisation of content by orchestrating the conceptualisation of concepts to enable learners to advance their analysis and conjecturing skills; and finally, (3) guiding conclusions to support learners in validating established conjectures for the application of knowledge and skills in problem-solving (Masilo, 2018). This study views heuristic strategies for teaching mathematics as facilitating active learner engagement in critical thinking, decision-making, and mathematical problem-solving skills and abilities (Kia, 2023). Furthermore, heuristic methods of teaching promote effective teaching and meaningful learning, positively influence mathematics performance, and improve students' achievement (Rwehubura & Kaponga, 2024; Ismoilova & Hamilova, 2019).

In agreement with the ideas surrounding the benefits of heuristic teaching strategies, this research highlights that heuristic methods of teaching, by fostering active engagement, self-regulated learning, self-control, self-direction, and learner-centred activities, enrich learners with skills that enable them to be responsible active participants throughout the mathematics lesson. This active engagement maximises learning, optimises allocated learning time, and keeps learners focused throughout classroom engagement, thereby reducing the likelihood of activities that contribute to irregularities during lessons.

2.2 The heuristics approach of sustainable problem solving

Heuristic advantages align properly with the forms of heuristic approaches that foster problem-solving skills. Heuristic approaches that contribute to a comprehensive problem-solving strategy include the affective, availability, and representative heuristics problem-solving approaches (Corporate Finance Institute (CFI), 2022). The three forms of heuristics' impact on problem-solving are as follows: (1) the affective heuristics problem-solving approach is inclined towards decision-making prompted by an individual's beliefs or prior knowledge; prior knowledge that is initiated by positive or negative feelings that are triggered by stimuli at the problem solver's exposure; (2) the availability heuristic approach towards problem-solving capitalises on judgements as suppositions triggered through acquired new information; and (3) representative heuristics, which hint at validating the feasible solution in association with another solution of the same nature (CFI, 2022). The outlined forms of the heuristics problem-solving approach indicate that problem-solving begins with exposure to some stimulation that aligns the problem that exists with previous experiences, where judgments on the existing problem scenario lead to hypothetical thinking that triggers new information to be used in validating the suppositions for solutions to the existing problem. Therefore,

it is evident that there is a dire need for relevant heuristic teaching strategies to enable sustainable problem-solving skills.

2.3 Heuristics versus the algorithm teaching strategy

The tasks of a teacher in the heuristics approach to the educational environment include providing and proposing the use of relevant resources, planning activities, developing background mathematical activities that enhance learning, and facilitating the learning process. In addition, Komatsu and Jones (2019) highlight that to support learners' heuristic processes, the following design principles apply: using activities with implicit purposes, providing learners with tools that can assist them in creating counterexamples, and supporting learners' realisation of contradictions.

Furthermore, the techniques of the heuristics teaching approach are outlined as discovery, experimental methods, project methods, role play, computer-assisted instruction, teamwork, and class discussions (Masilo, 2018). The author further highlights that in any heuristic method of teaching, the teacher observes and evaluates learners' understanding of the task and how suppositions are made and validated. Additionally, the objective of the heuristic method is for the teacher to support students in applying accuracy, scientific inquiry, analysis, and interpretation, and further to become confident and independent problem solvers (Patil, 2013). In contrast, algorithmic teaching approaches involve teacher-centred learning environments. This implies an environment where the teacher disseminates all the information to learners through explanations and definitions of concepts, making suppositions and validating them. Furthermore, assessment in algorithmic problem-solving encompasses using drill methods to enhance understanding and obtaining feedback from the teacher. The algorithmic approach to teaching is likely to present learners as passive receivers of information, where they take notes and answer or ask questions only when prompted by the teacher (Masilo, 2018).

Nonetheless, there is a bridge between the two teaching strategies. While it is important to facilitate learner-centred problem solving through learner engagement in self-regulated discovery and exploration, maximal teacher interaction or intervention for guidance in the learner self-regulated process is necessary to ensure the achievement of the envisioned common goal.

3. Theoretical Imperatives

From a constructivist lens, this research highlights that sustainable development in mathematics aligns with active learning, where a paradigm shift is needed for teachers to consider the maximal strategies of learner-centred teaching, balanced against teacher-centred teaching. This calls for teachers to apply teaching methods that support learners in building from existing knowledge and connecting to real-life situations; inculcating competence in linking concrete to abstract concepts in solving daily-life problems; and applying project-based and cooperative learning methods (Vintere, 2018; Doychinova, 2023). Teachers operating from a constructivist perspective in their classroom practices can channel classroom discourse towards interrogating and finding solutions to global challenges and promoting social justice (Malakar, 2023). This contributes to teaching that fosters sustainable learning for sustainable development. Sustainable learning relies on a comprehensive algo-heuristics strategy of teaching. Nonetheless, this research highlights that when the heuristic approach outweighs algorithmic instruction, sustainable learning is likely to manifest. Excessive algorithmic practice makes learning environments unsuccessful, as teachers are the owners of skills, knowledge, and resources that learners fail to access.

Schrage and Langlet (2016) articulated the theory of education for sustainable human development, which is the redefined education for sustainable development established by Landuf, Doscher, and Rocco (2008). According to Schrage and Langlet (2016), the theory of education for sustainable human development serves as a framework to assess education for sustainable development outcomes, teaching practices, and curricular knowledge and skills development. In essence, the theory of

sustainable human development focuses on (1) teachers' attention to contextual circumstances that impact learners' well-being; (2) teaching strategies that enable learners to perceive their capabilities; (3) teacher awareness of learner needs to create a learning space that allows learners to be who they are as they engage in the learning environment; and (4) teacher-learner democratic liberation to enable learners to identify their capabilities and cultural values that aligns with their immediate communities. Mathematics curricula must integrate societal, environmental, and economic issues to support students in comprehending the significance of mathematical decisions on the economy, society, and environment (Lestari et al., 2024). The authors further argue that integrating philosophies related to sustainable development in mathematics teaching and learning supports learners in engaging with mathematics in more meaningful ways and can contribute towards societies that are environmentally responsible. Regardless of the challenges evident in implementing education for sustainable development in mathematics classrooms, such as teaching time and learning resources, including comprehension of sustainable teaching and learning (Lestari et al., 2024), the obstacles hindering mathematics teachers from empowering learners with the knowledge, skills, and abilities to advance education for human sustainable development must be addressed through teacher empowerment. This involves empowering teachers with the abilities to integrate algorithmic and heuristic strategies of teaching into sustainable development philosophies to support learners' welfare in relation to independent engagement in learning and alignment of learning with social, economic, and cultural connotations.

4. Synthesis

The algo-heuristics teaching method focuses on prescription-oriented teaching versus process-oriented teaching. The history of mathematics teaching indicates that prescription-oriented teaching emphasises memorisation aimed at achieving end results. This approach often leads to underachievement, as many learners struggle with memorisation. In contrast, process-oriented teaching supports learning for knowledge acquisition by emphasising understanding of processes, with problem-solving as the outcome. The learning skills fostered by process-oriented teaching relate to (i) the transition from knowledge to skills and abilities; and (ii) self-regulation skills that contribute to knowledge acquisition. Teaching strategies suggested by Education for Sustainable Human Development (ESHD) are aligned with process-oriented teaching. Specifically, ESHD teaching strategies focus on (1) contextual circumstances; (2) supporting learners in recognising their capabilities; (3) awareness of learner needs; (4) creating spaces for meaningful learning; (5) promoting the democratic liberation of learners; and (6) linking learning with community needs. The anticipated learning skills and capabilities derived from ESHD-aligned teaching pertain to (1) learners' ability to perceive and identify their capabilities; and (2) learners' competency in recognising culturally valued functions within their communities to enhance mathematical problem-solving. This research on the challenges and successes of sustainable development shows that prescription-oriented teaching leads to dysfunctional learning environments, where both teachers and learners struggle to engage in sustainable mathematics teaching and learning. In contrast, process-oriented teaching aligned with ESHD characteristics fosters a functional educational environment, resulting in successful, sustainable teaching and learning of mathematics.

5. Research Methodology

Research design refers to a logical and systematic plan prepared for directing a research study (Khanday & Khanam, 2019). The authors further describe research design as a framework of methods and techniques that the researcher uses to combine various components logically to efficiently address the research problem and adopt strategies for achieving the study objectives. This study's conceptual blueprint—that is, the research design—translates from the constructivist paradigm, which highlights the researcher's comprehension of the meaning behind social phenomena, including human behaviour, and emphasises the importance of meaning in knowledge creation

(William, 2024). The constructivist perspective in this study acknowledges multiple realities, where different individuals and groups present the truth in more than one version in relation to their social contexts. Therefore, this study sought to explore the participants' experiences, interactions, and reflections on how they interpreted their immediate social world subjectively. Subjectivity aligns with qualitative inquiry; thus, a qualitative research methodology was employed to investigate the participants' lived experiences concerning the challenges and successes of mathematics teaching for sustainable development. The qualitative phenomenological study was conducted to interrogate the participants' subjective perspectives on the phenomenon of mathematics teaching for sustainable development, relating to both its challenges and successes. This study's population consisted of schools in the Tshwane North district of Gauteng. Ten schools were purposively sampled for the longitudinal study that lasted for three years; however, this report is based on one school, where six mathematics teachers who teach at both the senior phase and Further Education and Training (FET) phase, that is, grades 8-12, were engaged as voluntary participants. The six teachers participated in a focus group interview and were also observed while teaching mathematics in their classrooms. Of the six participants, four teachers were allocated to grade 10 classes; one teacher taught senior phase mathematics (grades 8 and 9), while the sixth teacher, who was the head of the mathematics department, was allocated only to grade 12. Therefore, observations were conducted in the grade 10 classrooms, where most of the voluntary participants were allocated, and a common topic of functions was taught.

Focus group interviews were conducted to establish the teachers' views on classroom factors that enable or hinder their teaching of mathematics. The questions used by the researcher to encourage group interaction were aligned with process-oriented teaching, specifically in relation to lesson planning, learner motivation, performance, learning activities, and teacher-learner interaction. The five open-ended questions posed were: (1) What factors do you consider when planning lessons? (2) What is your perception of learners' motivation towards the mathematics learning area? (3) What is your perspective on learner performance in mathematics? (4) How do you administer activities or learning tasks in your classroom? (5) How do you facilitate learner engagement during the lesson?

Before the teaching of the Functions content area could commence and observations be conducted, discussions were held between the observer and grade 10 teachers to agree on the mode of presentation, specifically the process-oriented lesson. They also reached an agreement on the utilisation of available resources and the preparation of PowerPoint presentations by the teachers for demonstration, explanation, and to encourage peer discussions, as well as teacher-learner interactions. Observations were conducted to evaluate the successes and challenges associated with the implementation of process-oriented lesson presentations. Thematic data analysis was employed to explore the participants' lived experiences and to understand the successes and challenges of implementing process-oriented teaching strategies in mathematics for sustainable development. The thematic analysis was used to identify, analyse, and interpret the patterns that emerged from the data.

This research report is part of a longitudinal study focused on the application of inquiry-based learning as a heuristic method to empower grade 10 learners with inquiry-based learning skills relevant to advancing mathematical problem-solving. Ethical clearance for the longitudinal study was granted by the College of Education at the University of South Africa. Ethical protocols, including anonymity and confidentiality, were adhered to in the report. Participants provided consent, and parent consent for the learners was sought; learners were also requested to assent to participate in the study while they were observed interacting with their teachers.

6. Presentation of Findings

Findings are reported based on classroom observations and focus group interviews. The focus group interview aimed to identify the successes and challenges experienced by teachers related to learner

motivation, performance, classroom tasks, teacher-learner interactions, the provision and usage of teaching and learning resources, and the planning of activities. The observations aimed to ascertain the teacher perceptions that emerged from the focus group interview, including how teachers facilitate learning and interactions to achieve the algo-heuristics methods of teaching and learning. This also included examining the usage of available resources in alignment with concrete to abstract learning.

6.1 Focus group interview

Planning lessons for an appropriate teaching process was discussed, where teachers were asked about the factors they consider when planning lessons. It was revealed that the lesson plans used are provided and included in the curriculum documents supplied by the subject advisor. Teachers agreed that they do not adapt the guide provided as a lesson plan but use it as is. Some teachers highlighted that they follow the annual teaching plan (ATP); therefore, they do not have a specific lesson plan drawn up to guide them in facilitating learning according to the needs of the specific learners and the environment they are exposed to.

To explore the learner characteristics of motivation towards sustainable learning, teachers were requested to comment on learner motivation in the learning area of mathematics. All six teachers agreed that learners lack motivation towards their studies in mathematics. Characteristics highlighted by teachers as signs of a lack of motivation include (a) a negative attitude, for example, where a learner makes statements such as, *I will pass other subjects; it does not matter if I do not pass mathematics*; (b) a lack of adaptation to new knowledge; (c) a lack of interest in participating in classroom activities, such as not writing or completing prescribed tasks; and (d) a lack of resources during lessons, meaning learners do not regularly bring the distributed resources. The causes of the highlighted characteristics of lack of motivation were outlined as (a) a lack of background mathematics, including a lack of skills and knowledge from lower grades; (b) a lack of resources during classroom interaction; (c) minimal school-based support for mathematics classrooms; and (d) a lack of parental involvement.

Performance in mathematics pertains to the ability to apply relevant skills and knowledge to find solutions for presented or encountered problems. To explore learners' abilities to apply skills and knowledge to solve problems, teachers were asked to respond to the issue of learner performance in mathematics. Teachers shared the same views that the Grade 10 learners in their classes struggle with different facets of learning, thus meaningful learning cannot be advanced. The mentioned challenges were outlined as (a) content acquisition, where Algebra was noted as the main challenge, hence *all content areas are affected as Algebra is applied in all content areas*; (b) the language of learning mathematics differs from the learners' socialisation language, therefore learners are learning the language of instruction alongside the mathematics content; and (c) a lack of concentration, where learners fail to link basic concepts taught with advanced concepts.

Teachers attributed all shortfalls to learners and did not indicate where they were falling short as classroom managers. Consequently, a follow-up question was posed by the researcher: Where do teachers fall short in improving the situation and assisting learners to overcome the challenges? Acknowledging that they are also responsible for learners' shortcomings, the group agreed, and one teacher echoed, *as a teacher, I must ask myself, do I also teach them to learn in a better way*. Therefore, teachers agreed that learner struggles are the effects of instructional ineffectiveness. Furthermore, they highlighted the need for professional development to cope with classroom circumstances. Teachers acknowledged that they need re-skilling to acquire the skills necessary to transform mathematics teaching to meet contemporary teaching needs.

Learning tasks are important to enable learners to apply acquired skills and knowledge to showcase their capabilities. Participants in the focus group were asked about how they administer learning

tasks. Teachers highlighted the challenges of engaging learners in classroom tasks (classwork) and after-hours/at-home practice tasks (homework). Teachers face challenges in conducting activities with learners in the classroom, as occasionally, teaching time is consumed by attempts to maintain discipline and foster learner attention. Consequently, teachers are left with no choice but to assign work for learners to complete after hours, mostly at home. Teachers' direct concerns and comments on learning activities are outlined in Table 1.

Table 1: *Teachers' comments on learning activities*

- *Only a few complete the activities; the majority do not write prescribed after-hours activities; they copy in the morning.*
- *I end up leaving those who do not write and focus on the few who do the work*
- *The majority do not do the work, either in the classroom or for homework.*
- *Only a few learners write and complete the tasks.*
- *It is a trend, most learners do not complete after-hours activities assigned to them, in all subjects, the challenge is not only in mathematics.*
- *If you apply disciplinary measures to the learners for not doing the homework, you will lose the whole mathematics period.*

Teacher and learner interactions appear to influence either a prescription-oriented or process-oriented education system. Participants were asked about how they engage learners during their mathematics lessons. Responses indicated that, while there are struggles, teachers make significant efforts to foster a learner-centred classroom. Teachers noted that they use question-and-answer methods to deliver lessons and also indicated that they employ reflective pedagogy in their interactions. Nonetheless, they admitted that they need empowerment regarding teaching strategies for meaningful learning. Teaching and learning media play an essential role in the teaching of mathematics, contributing to the advancement of process-oriented teaching. The available teaching and learning media that participants reported included textbooks and gadgets (laptops) for both teachers and learners. Focus group interviews revealed that challenges related to learner motivation, performance, teacher-learner interactions, the administration of learning tasks, and teaching and learning media are often overlooked by teachers during lesson planning; consequently, prescription-oriented teaching overshadows process-oriented teaching.

6.2 Observations

A structured checklist was utilised to record both heuristic and algorithmic occurrences that emerged from teacher-learner interactions. Observations were conducted in grade 10 classes; therefore, four participants, who were the majority of voluntary participants, were allocated to grade 10 classes and were observed during their classroom interactions with learners. The other two participants were allocated to grade 8 and grade 12, respectively, and participated only in a focus group interview that involved all mathematics teachers in the sampled school. An observation schedule was used. The checklist in Table 2 outlines the patterns that emerged as the four teachers taught the Functions content area of mathematics. The ticks indicate Yes (Y) or No (N), while P shows that the characteristic was partially conducted.

Table 2: *Checklist-algorithmic versus heuristics teaching*

Algorithmic Characteristics	Y	N		Heuristics Characteristics	Y	N
The textbook is the only resource	X			Teacher instigating the usage of resources. (laptop, tablet, smartphone)		X
Teacher explains/defines all concepts and relies on own knowledge and disseminates all information.	X			Application of experimental method; project method; role play, and computer-assisted method		X

Learner is passive, takes notes, and few participate only when asked to participate.	X			Skilfully administers teamwork and class discussion		P
The teacher makes suppositions and validates them. Teacher autonomy plays a key role.	X			Teacher prompts to encourage the learner's ability to learn by exploration and discovery.		X

Based on the results in Table 2, algorithmic practices dominate heuristic practices in the teaching of mathematics. More facts were gathered through observations regarding the availability and usage of resources, teacher-learner interaction, learning tasks, and evidence of lesson planning. Teachers strive to do the majority of the teaching, while learners are passively involved. Teaching is centred around traditional methods, where only a textbook is regarded as the classroom resource. Teachers believe that they are the only ones who can explain concepts effectively to save teaching time. Similarly, learners look to the teacher as the sole source of knowledge and lack confidence in their own abilities to create knowledge.

Table 3: *Observation items and environment status*

Observation item	Environment status
Availability of resources	Few learners bring their laptops and textbooks to class; the majority leave their materials at home. The ones with laptops had no books; and those who had books did not have laptops. The content contained in laptops is the electronic version of the same content as the textbook. In a way, learners were using the laptop to access the e-version of the textbook and other material that can be accessed as hard copies. No other programmes are loaded on the learners' laptops.
Teacher and learner interaction	Formal classroom, where only the teacher is the main participant. Learners listen and take notes where possible. Few learners participate during the question-and-answer sessions. Most learners could not respond in any way to the teachers' facilitation. Disruptions like learner-learner chat, and learner posing jokes and regular laughing from learners were disruptive and diverted the teacher's attention from giving instruction, but to an effort to keep order and attention through reprimanding learners.
Learning tasks	Learners participate in writing prescribed classroom activities, however, there were indications that they present incomplete work and cannot cope with the workload given for individual attention.
Teacher Planning of lessons	No planning was evident in all observed lessons. Teachers rely on their experience to teach. For example, all the teachers maintain one method of teaching, that is teacher centred, that does not cater for individualised learning and inclusivity. Teachers display good content knowledge; however, pedagogy relies on purely algorithmic methods of delivering the content.

Skills and a focus on integrating available resources are essential. A learner-centred approach is not possible when teachers do not use available resources to advance the heuristic characteristics of learning. Diversity in learning is hindered, and exploration to support logical reasoning is compromised. A teacher-centred approach dedicates more time to attempts at fostering learner participation and attention. Learners' lack of response to activities and questions posed by the teacher indicates a lack of knowledge, particularly of basic concepts. It further demonstrates a lack of understanding of the content presented by the teacher. Learner-to-learner conversations that do not align with the teacher's presentation reflect a lack of discipline during the lesson. Discipline is crucial in learning mathematics. A lack of discipline inhibits engagement and focus, resulting in learners attending class without achieving any learning goals.

A teacher-centred mode of facilitation creates more dependent learners. Learner dependency on the teacher hampers self-regulation when they must complete tasks for evaluation. Learners are diverse and possess different ways of learning. A single method of teaching for every lesson and every content area or topic excludes some learners who may struggle with only listening and taking notes.

Learners' eagerness to explore needs to be harnessed, and it is imperative that each learner's way of thinking and doing things is supported. Teachers must develop skills to (1) motivate learners; (2) control ill-discipline; (3) facilitate a learner-centred environment; (4) support active learner participation; and (5) integrate resources to achieve learning goals and encourage positive responses toward completing classroom activities. These challenges hinder heuristic methods of teaching that require active learner engagement. Learner engagement in content discussions and the ability to explore necessitate discipline and a desire to achieve learning goals. Nonetheless, intense teacher intervention is necessary to guide learners in understanding the mission of the mathematics classroom. A lack of understanding of the main lesson and classroom goals detracts from learners' focus on self-regulation and metacognition needed to achieve learning goals. Learners' lack of discipline leads to chaotic classrooms that undermine focus and hinder the attainment of learning goals. This lack of discipline reduces concentration spans and triggers a further decline in adherence to classroom policies.

7. Discussion

Findings in this study suggest that the challenges to sustainable teaching of mathematics outweigh the successes. Specifically, the factors that hinder process-oriented and algo-heuristic teaching aimed at sustainable development overpower those that facilitate sustainable development-oriented teaching. Literature highlights the successes of mathematics teaching for sustainable development as being related to the learning skills that process-oriented teaching yields, which include (i) the transition from knowledge to skills and abilities, and (ii) self-regulation skills for knowledge acquisition. Teaching strategies suggested by the ESHD are aligned with process-oriented teaching. These ESHD teaching strategies focus on (1) contextual circumstances, (2) supporting learners in perceiving their capabilities, (3) awareness of learner needs, (4) creating space for meaningful learning, (5) democratic liberation of learners, and (6) linking learning with community needs. The envisaged learning skills and capabilities produced by the ESHD-aligned teaching pertain to (i) learners' ability to perceive and identify their capabilities and (ii) learners' competency in identifying community-valued functions to advance mathematical problem-solving (Scrage & Langlet, 2016). Observation has shown that the ESHD strategies are not viable in the research area of this study. This is evident because teachers faced challenges in implementing process-oriented lessons that are algo-heuristic, as discussed and planned in a preparatory group discussion to prepare all teachers to circumvent prescription-oriented teaching, which is algorithmic teaching.

Research confirms that maintaining learners' motivation in mathematics learning is challenging, although motivation is essential for student success and is related to behaviour and achievement (Sadaati & Celis, 2023; Pantziara & Phillipou, 2015). Data findings in this study indicate that the causes of lack of motivation highlight the need for implementing strategies that can elevate students' motivation and courage to enhance self-regulated learning for interaction and knowledge acquisition. Such strategies include teaching that equips learners to bridge the gap between knowledge they may have unsuccessfully acquired in lower grades and the knowledge they must acquire in grade 10, which relies on foundational knowledge from lower grades. Furthermore, resources must be made available for learners' optimal usage. During observations, it was evident that laptops had been distributed to learners (cf. Table 2); however, they could not use the devices for learning due to a lack of internet access. It is essential that teaching prioritises the maximum utilisation of every resource available to learners. The mentioned lack of school-based support refers to the provision of resources and moral support by school authorities.

The facilitation of learning should prioritise methods that assist learners in coping with language imperatives, both mathematical and instructional. Addressing such imperatives can enhance learners' mathematical conceptual understanding. A teacher should be a lifelong learner, meaning they must have opportunities for ongoing development and growth in learning (Friedkin, 2022).

Teachers acknowledged that their teaching has implications for learners' challenges in learning mathematics. Therefore, if they were to empower themselves regularly, they would be better equipped to meet the demands of 21st-century teaching and learning needs. It is necessary for teachers to be empowered to teach in diverse environments and apply relevant teaching methods in each content area, for example, scrutinising and utilising resources relevant for teaching Algebra and those relevant for teaching Geometry.

7.1 Alleviating challenges to advance sustainable teaching

To advance mathematics teaching that instils in learners the 4IR skills in preparation for the demands of the 5IR era, it is critical that teachers are empowered to implement process-oriented heuristics teaching strategies aimed at (1) supporting learner motivation and discipline for self-regulated learning, and the ability to thrive in collaborative learning; (2) integrating available resources to empower learners with self-regulation, exploration, and inquiry skills. It is a success that the basic education ministry has managed to provide teachers and learners with digital resources such as laptops and aligned software. Nonetheless, training is needed to enable teachers to adopt heuristic teaching strategies that facilitate (i) a learner-centred approach; (ii) learners' capabilities for exploration to support logical reasoning; and (iii) diversity to meet all learners' needs and capabilities for the advancement of sustainable learning.

To minimise the challenges that inhibit productive teacher-learner or learner-learner interactions, there is a need for teaching strategies that involve learners as active participants through exploration facilitated by digital gadgets. Involvement in knowledge discovery and hands-on exploration must be considered to keep learners continuously engaged and interested in the development of concepts and processes of problem-solving. This could help learners become independent in their learning rather than dependent on the teacher. Dependency leads to passivity. Empowerment is necessary to assist teachers in adapting to 4IR teaching skills by moving away from pre-4IR teaching methods. In planning mathematics lessons, diversifying resources and presentation strategies across various content areas must be prioritised. Therefore, teachers must be empowered to develop lesson plans tailored to the specific needs of each content area. Teachers need to be made aware that every content area requires relevant resources and strategies to emphasise specific content area-based concepts.

7.2 Implications of the findings for sustainable development

The study findings implicate the teaching practice theory, curriculum, and educational policy in education that should align with human sustainable development goals. Teaching that advances human sustainable development focuses on practices that integrate societal, environmental, and economic contexts. Such practices support students in engaging meaningfully in their learning by enabling them to make mathematical decisions in finding solutions to societal, cultural, and economic problems. This aligns with teaching that enables learners to attain cognitive growth towards environmental responsibility. The findings show that when learner-centred teaching cannot be advanced, mathematics teaching for sustainable development becomes unattainable. Therefore, the value of education in supporting human sustainable learning is adversely impacted. The learner's well-being, based on democratic dialogue and consideration of cultural and societal contexts towards the development of the learning experience, cannot be advanced. Heuristic teaching methods are essential for teaching sustainable learning. Consequently, teaching that relies solely on algorithmic strategies, excluding the heuristic aspect, hinders sustainable learning and the advancement of active learner engagement in critical thinking, decision-making, and mathematical problem-solving. This, in turn, obstructs meaningful learning, which is vital for good performance and learners' achievement. The study findings further imply that curriculum transformation is essential in school mathematics, where policy amendments are needed to include algo-heuristic teaching strategies that can outline appropriate practices to support sustainable human development. This would enable the

successful grounding of the learned cohort to attain and apply 5IR competencies for the achievement of Mission 2030 for sustainable development.

8. Conclusion and Recommendations

Teaching for sustainable learning geared towards 2030 sustainable development skills is currently facing more challenges than successes in mathematics classrooms within the South African context. This indicates that the teaching of mathematics struggles to instil the 4IR skills necessary to equip the current cohort of learners with 5IR-relevant sustainable development skills for problem-solving, in alignment with efforts to alleviate ongoing economic, social, and environmental issues. Despite the teaching challenges outlined, this study argues that a change in teaching strategies towards sustainable practices is possible. This possibility should be supported by reskilling teachers to enable them to apply relevant 4IR teaching strategies while utilising available resources to facilitate sustainable learning in the digital era. Furthermore, this study emphasises the importance of empowering teachers to apply heuristic methods of teaching to support sustainability in learning mathematics. While teachers must learn sustainable teaching methods, they should also minimise algorithmic approaches to align with heuristic methods. The alignment of algorithmic and heuristic teaching methods enables teachers to advance algo-heuristic methods for guided inquiry, supporting learners who require teacher guidance in process-oriented learning. In essence, teachers should be coached and empowered to apply sustainable teaching strategies that promote learning aligned with process-oriented approaches for developing mathematical problem-solving skills geared towards sustainable human development.

9. Declaration

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