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ESG-Aligned OER Innovation for Sustainable Teacher Education

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Abstract

Many South African schools face educational resource shortages that hinder effective teaching and learning. This study investigates a community-driven Open Educational Resources (OER) initiative implemented within a teacher education programme at a South African university, where Bachelor of Education (BEd) students (n = 400) from first to fourth year across the Vanderbijlpark and Potchefstroom campuses were engaged in designing sustainable Learning and Teaching Support Materials (LTSM) from recyclable materials. A purposively selected qualitative subsample (n = 53) participated in the study. Framed within an interpretivist and qualitative phenomenological design, data were collected through structured written reflections capturing participants' experiences of the project. The findings show that creating OER from recyclable materials strengthened resourcefulness, collaboration, and awareness of educational inequality, while also encouraging more accessible and context-responsive teaching practices. The study contributes to understanding how Environmental, Social, and Governance (ESG)-aligned operational innovation can foster self-directed learning and sustainable teacher education in under-resourced contexts.

Keywords: Environmental, Social, and Governance (ESG); Open Educational Resources (OER); collaborative learning; Learning and Teaching Support Materials (LTSM); recyclable materials; self-directed learning; sustainable education; teacher education; under-resourced schools

1. Introduction

The global transition towards a net-zero future requires systemic operational shifts across all sectors of society, including the education sector. This net-zero future is an innovative framework for education that focuses on sustainability, flexibility in the face of climate change, and community engagement, which is increasingly recognised as a "living laboratory" for sustainability [1]. The integration of Learning and Teaching Support Material (LTSM) that is produced from recyclables acts as a critical entry point for this transition.

To achieve the Sustainable Development Goals (SDGs) of the United Nations, especially Quality Education (SDG 4) and Reduced Inequalities (SDG 10) [2], educational ecosystems should be sustainable, resilient, equitable and ecologically conscious. Therefore, education should not be understood as separate from larger sustainability concerns, but rather as one of the sectors within which such operational shifts should also occur. However, traditional educational resource provision often remains dependent on commercially produced textbooks, which may be costly and unevenly accessible in under-resourced contexts [3,4]. This creates a need for more affordable, adaptable, and locally responsive alternatives, such as OER and context-specific LTSM. This centralised and commercially driven model is especially problematic in resource-constrained environments, where the

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cost and uneven availability of educational materials may deepen existing inequalities and leave marginalised learners without adequate learning support [3–5].

In the South African context, this challenge is especially significant, as the country continues to face substantial difficulties in providing sufficient educational resources, especially to under-resourced schools [5]. Learning and Teaching Support Materials (LTSM) play an important role in the teaching and learning process and, if these materials are selected carefully, they can contribute to learners' mastery of subject-specific knowledge while also supporting their ability to learn independently [6]. However, when suitable pedagogical resources are lacking, teachers experience additional strain, learners' educational experiences are weakened, and educational gaps widen further. Therefore, overcoming such limitations requires the development of authentic LTSM that takes learner needs, real-life relevance, accessibility of materials, and the cultivation of critical thinking and creativity among learners and teachers into account [7]. In this project, LTSM included low-cost, locally made teaching aids such as cardboard flashcards, posters, subject-specific charts, recycled bottle-top counters, cardboard clocks, puzzle boards, word walls, matching cards, tin-can models, and three-dimensional visual aids constructed from recyclable materials. These resources were designed to support concept explanation, learner engagement, practical demonstration, and classroom participation in contexts where commercially produced resources may be limited.

In response to this need, community-driven Open Educational Resources (OER) initiatives present a possible scalable and Environmental, Social, and Governance (ESG)-aligned operational shift. In alignment with the global Recommendation on Open Educational Resources [8], such initiatives fulfil the "Social" and "Governance" mandates of ESG through the democratisation of knowledge and by addressing capacity-building, policy, and inclusive access. Furthermore, when the creation of OER is combined with the principles of the circular economy, and specifically with the physical construction of LTSM by using recyclable materials, it also directly addresses the "Environmental" mandate. In this regard, the use of recyclable materials not only supports conservation efforts but also empowers student teachers to innovate within the immediate and constrained environments in which they find themselves.

Crucially, this shift from resource dependency towards sustainable co-creation may also act as a strong pedagogical catalyst for Self-Directed Learning (SDL). Classical SDL theory frames self-direction both as a process and as a learner attribute [9], while later models place emphasis on the social-constructivist interplay between autonomy and collaboration [10]. Therefore, when student teachers engage in collaborative creativity in order to build LTSM from waste materials, they are forced to construct knowledge actively, solve complex logistical problems, and take cognitive responsibility for their own learning. In other words, the operational activity itself may become pedagogically meaningful.

Despite extensive research on the cost-effectiveness of OER [3] and the psychological aspects of SDL, there is a clear lack of qualitative studies on how these two interact in community-driven educational contexts. Most work examines OER adoption or SDL development separately, and there are few qualitative accounts that centre the voices of learners and teachers in under-resourced settings [11,12]. Thus, although OER and SDL are well studied individually, their relationship, particularly in under-resourced and community-driven contexts, remains underexplored. This study investigates how collaborative creativity fosters self-directed learning and critical thinking in under-resourced schools through a community-driven OER LTSM project. By capturing the lived experiences of student teachers, the study seeks to provide insights into how sustainable operational practices can contribute to the transformation of marginalised educational settings. In this regard, the value of the study lies not only in what it can reveal about OER or SDL

individually, but also in what it can reveal when these two are examined together within under-resourced educational contexts. Therefore, the study may deepen understanding of how community-driven and sustainable practices can support learning and educational development in contexts where such support is often needed most.

2. Synthesis and Research Gap

The current literature across the domains of Open Educational Resources (OER), Self-Directed Learning (SDL), and Education for Sustainable Development (ESD) reveals strong individual frameworks. However, it also highlights important intersections that remain underexplored. Existing research comprehensively documents the capacity of OER to democratise access to knowledge and reduce educational costs, particularly through large-scale initiatives in the global south, such as the Research on Open Educational Resources for Development (ROER4D) project [11]. ROER4D, the name of a network of 100 researchers and 21 countries, has become synonymous with high-quality OER research from the South. Furthermore, theoretical links between open educational practices and the cultivation of learner autonomy and SDL are increasingly being recognised in South African higher education contexts [12].

However, when these bodies of work are synthesised critically, three distinct research gaps become visible, and these are the gaps which the present study addresses.

Firstly, much of the existing OER literature in sub-Saharan Africa focuses on the adoption of Global North resources or on barriers relating to digital infrastructure. Less attention is paid to the localised and grassroots creation of context-specific materials. Van den Berg and Du Toit-Brits [12] note that the flow of OERs is mostly in one direction, that is, the context of developed to developing countries remains predominantly unidirectional, that is, from North to South, indicating that there is a pressing need for empirical research on community-driven development models in under-resourced settings. Therefore, while access remains important, the creation of materials within such contexts remains insufficiently explored.

Secondly, although the integration of principles of circular economy in education is gaining traction, such integration remains mainly localised within theoretical higher-education curricula, especially in fields such as engineering and business management, rather than within applied pedagogy in basic education [13]. There is still a paucity of research that examines the operational impact of physically creating Learning and Teaching Support Materials (LTSM) from recycled waste as a scalable and ESG-aligned educational practice. In this regard, circularity is often discussed conceptually, but not always enacted materially in pedagogical settings.

Third, recent studies place an emphasis on the role of digital circular economy practices in significantly improving both operational sustainability and educational outcomes [14]. However, there is virtually no qualitative evidence that explores how this specific operational shift, namely, collaboratively building physical LTSM from recyclable materials and then translating them into digital OER, functions as a pedagogical catalyst for the development of SDL and critical thinking in marginalised schools. Most existing studies still tend to examine either the efficacy, cost, usage, and perceptions of OER [3,4] or the psychological and self-regulatory dimensions of SDL [10,15], rather than exploring how OER co-creation, sustainability-oriented practice, and SDL intersect in under-resourced teacher education contexts. Therefore, by making use of a qualitative phenomenological design, the present study addresses the identified gaps by capturing the lived experiences of student teachers working at the nexus of ESG operational innovation, OER co-creation, and self-directed learning in under-resourced South African schools.

3. Conceptual Framework: The OER-ESG-SDL Nexus

To investigate systematically how operational shifts towards sustainability influence pedagogy in under-resourced environments, this study is anchored in a tripartite conceptual framework, as shown in Figure 1.

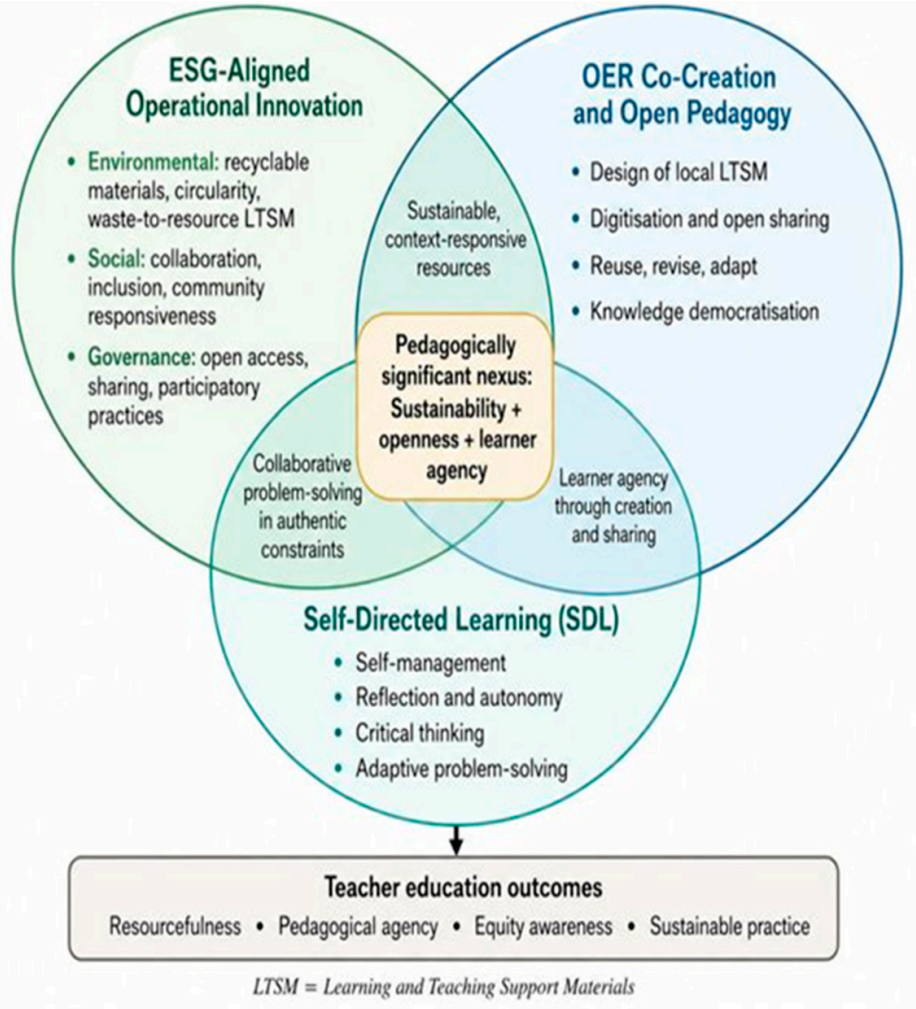

Figure 1. The OER-ESG-SDL Nexus.

The figure illustrates the relationship between ESG-aligned operational innovation, OER co-creation, and self-directed learning (SDL). ESG principles are operationalised using recyclable materials, collaboration, community responsiveness, and open-access practices. OER co-creation is reflected in the design, digitisation, sharing, and adaptation of locally developed LTSM. These processes create opportunities for SDL by requiring student teachers to engage in self-management, reflection, critical thinking, and adaptive problem-solving. The central overlap represents the pedagogically significant nexus where sustainability, openness, and learner agency intersect to support resourcefulness, pedagogical agency, equity awareness, and sustainable teacher education practice.

Drawing from the literature review, the article integrates constructivist adult learning theory, the global open education mandate, and models of Education for Sustainable Development (ESD). In this regard, the OER-ESG-SDL Nexus is proposed in order to illustrate how community-based OER creation does not function merely as a content solution, but also as a social process through which self-directed learning (SDL) may be nurtured, and sustainable education may be advanced. The framework, therefore, consists of three intersecting dimensions.

3.1. Constructivist SDL Theory

The framework's premise is based on the understanding of learner autonomy as both an individual characteristic and an interactive process. Classical SDL theory considers self-direction as the capacity of learners to diagnose their needs, seek resources, and assess their progress [9,16]. In under-resourced settings, however, it is necessary to move beyond individualism alone. Subsequent models place emphasis on the social-constructivist interaction between autonomy and collaboration [10], while self-regulated learning (SRL) models emphasise the ongoing cognitive monitoring required during complex tasks [15].

In the present study, collaborative creativity, namely the physical design of Learning and Teaching Support Materials (LTSM) by using recyclable materials, acts as the catalyst. It forces student teachers to enact these SDL competencies in a collaborative manner and therefore bridges the gap between individual agency and communal scaffolding. Specifically, participation in the project may inherently integrate self-management, self-monitoring, and motivational dimensions [10]. Therefore, the pedagogical engine of the framework lies not only in what the student teachers make, but also in what they must do cognitively and socially in order to make it.

3.2. OER and Open Pedagogy

The digitisation of the physical LTSM into Open Educational Resources introduces the second dimension of the framework. This aligns directly with the 5-Action Area Framework outlined in the Recommendation on Open Educational Resources [8], particularly in relation to capacity-building, inclusive access, and sustainability. Moving from passive consumers of commercial textbooks to active creators of knowledge, student teachers engage in what has been conceptualised as "open pedagogy" [17] and also as a "pedagogy of open hope" [18]. Therefore, the process is not only about access to content, but also about a shift in educational positioning.

When this process is evaluated through frameworks such as the COUP model, namely Cost, Outcomes, Usage, and Perceptions [4], it becomes possible to see how open licensing and distribution of these materials fulfil the "Social" and "Governance" mandates of ESG. In this way, systemic control is shifted to local educational communities. However, this shift is not only technical. It is also pedagogical, social, and governance-related in nature, because the act of creating, sharing, and contextualising resources changes the role of the student teacher as well as the educational environment in which that student teacher operates.

3.3. Education for Sustainable Development

The final dimension places the operational parameters of the project within the broader mandates of the Sustainable Development Goals of the United Nations and the Agenda 2063 of the African Union. The transition to net-zero operations requires not only theoretical knowledge but also applied and transformative learning that reshapes the way human beings interact with the environment [19,20]. Therefore, by requiring the use of authentic and recyclable materials for the construction of LTSM [7], the project embeds circular economy principles, that is, the "Environmental" pillar of ESG, directly into the curriculum.

This waste-to-resource approach embeds circularity directly into the practice of student teachers and, in doing so, shifts their operational mindset from one of resource dependency towards one of sustainable innovation. In other words, sustainability is not only spoken about theoretically but is enacted materially through pedagogical practice. Therefore, the environmental base of the framework does not separate from the pedagogical and governance layers but rather intersects with them in ways that may support more meaningful, more sustainable, and more self-directed forms of learning.

4. Methodology

4.1. Research Design and Paradigm

Framed within an interpretivist paradigm, the present study employed a qualitative phenomenological research design. This design was regarded as suitable for the study because a phenomenological approach is concerned with capturing and exploring the lived experiences of individuals, as well as the subjective meanings that such individuals attribute to a particular phenomenon [21]. In this regard, the approach was appropriate because the study did not seek only to identify what happened in the project in a general sense but also to identify how the participants themselves experienced and understood what was happening.

In the present case, this allowed the researchers to investigate how student teachers internalised circular economy practices and how this operational change influenced their pedagogical autonomy and self-directed learning. Therefore, the value of the phenomenological approach lies not only in describing the activities that were undertaken, but also in making it possible to understand how those activities were subjectively experienced by the participants and what meanings they attached to them. In the same way, the design allowed the study to move beyond simple description and towards an understanding of how operational change can become connected to pedagogical development and to self-directed learning in the lived experiences of student teachers.

4.2. Participants and Context

Research was undertaken at the Faculty of Education at the North-West University in South Africa, Vanderbijlpark (VC) and Potchefstroom (PC) campuses. The population included all Bachelor of Education (BEd) students (n = 400) in the School of Commerce and Social Studies in Education. They were at various levels (first to fourth year) and were selected purposely for their involvement in teaching practice (TPrac) in under-resourced school environments where Learning and Teaching Support Materials (LTSM) are scarce. Purposive sampling was used in the study. Through this sampling approach, student teachers were selected and tasked with collaboratively designing LTSM entirely from recyclable materials. The criteria for inclusion included being enrolled in a BEd student-designated programme(s) and campuses and having engaged in the OER-LTSM project. A subset of this group (n = 53) was drawn to secure reflective and rich data. This sample was deemed suitable as they are student teachers and active participants in "live" classrooms, which allows them to connect with innovative pedagogic practice and the contextual constraints of a resource-poor environment. As part of the process, participants were also required to record detailed planning together with photographic evidence of the process and the materials that were created. The information was then uploaded to a dedicated digital platform.

The purpose of the digital platform was to enable open access so that others could see, use, and adapt the developed LTSM in their own situations. In this respect, the initiative focused not only on the production of materials but also on their availability beyond the immediate project environment. A smaller group of participants (n = 53) was selected from the larger project cohort in order to support a more focused qualitative study. This sample provided a rich and localised context for examining how future educators can innovate within severe resource constraints to build sustainable and ESG-aligned educational resilience.

4.3. Data Collection Strategies

Data were collected using a qualitative instrument that required critical written reflections from the participants. After the physical construction of the LTSM made from recyclable materials was completed, the participants were required to complete structured written reflections. These reflections captured the operational and "Environmental" dimensions of the project by documenting the sourcing of recyclable materials, the collaborative problem-solving that was required to repurpose such materials, and the changing perceptions related to the use of sustainable materials. In this regard, the reflections were important because they not only recorded what the participants did, but also how they understood and responded to the process of working with recyclable materials in the project.

4.4. Data Analysis

The data collected, which comprised 53 written reflections, were analysed using ATLAS.tiTM software (Atlas.ti25 25.0.1.32924). The study followed the phases of inductive thematic analysis as outlined by Braun and Clarke, namely identifying, analysing, and reporting patterns (themes) within data [21]. To ensure that the analysis remained grounded in participants' own accounts, an inductive approach was used. Initial open coding allowed emergent and participant-driven themes related to collaborative creativity to surface organically from the data itself. In this regard, the analysis did not begin with predetermined categories only, but allowed patterns and meanings to emerge from what the participants reflected on in their written responses. Therefore, the use of inductive thematic analysis was important because it allowed the voices and experiences of the participants to shape the findings in a more direct way.

4.5. Trustworthiness and Ethical Considerations

The integrity was maintained in accordance with qualitative standards for trustworthiness: credibility, transferability, dependability, and confirmability [22]. Direct, thick descriptions of the participants' experiences are provided to allow readers to assess transferability to other resource-constrained contexts. Furthermore, the researchers practiced active reflexivity throughout the process to mitigate subjective bias [23]. The study received full ethical clearance from the institutional Research Ethics Committee. To uphold the ethical mandate of non-maleficence and autonomy, participation was strictly voluntary, informed consent was obtained, and all data were de-identified using pseudonyms to ensure confidentiality.

5. Findings: Operationalising the OER-ESG-SDL Nexus

Thematic analysis of the participants' reflections yielded five primary themes that can be interpreted through the proposed OER-ESG-SDL Nexus. The findings suggest that the physical and environmental constraints of building Learning and Teaching Support Materials (LTSM) from recyclable materials encouraged resourcefulness, collaboration, community responsiveness, critical thinking, and a shift from task completion to a broader educational purpose. In relation to Garrison's [10] model, these findings point especially to the development of self-management and motivation, while also indicating reflective and socially mediated dimensions of self-directed learning. The discussion of the themes is supported by verbatim quotes from the participants' reflections. The identifiers were created as follows:

- The first four numbers are the birth date
- The second last three are the final numbers of the student number
- The last three numbers are the first three letters of their surname

5.1. Theme 1: Seeing Recyclable Materials as Teaching Resources

A major theme in the data was a shift in how participants viewed recyclable materials. What was initially described as impractical or even "impossible" was later understood as something that could be used to create meaningful teaching resources.

5.1.1. Sub-Theme: Starting with Uncertainty

Teachers often regard commercially produced materials as more valid and effective than locally sourced or improvised materials [24]. Participants entered the project with uncertainty because they did not initially believe recyclable materials could be turned into useful classroom resources.

> *"The first thing that was on my mind was, how are we going to create an ltsm, I initially daw it as an impossible task." (0413663LEK)*

> *"I was so sure that recyclable materials cannot be used as useful tools in classroom." (0624238NON)*

Once participants moved beyond this initial uncertainty, their attention shifted to the practical problem of finding enough suitable materials.

5.1.2. Sub-Theme: Finding Suitable Recyclable Materials

Teachers often have to work with what is available and adapt when ideal resources are not accessible, which encourages context-based and hands-on development of teaching materials [25]. Participants described having to search for specific materials, decide what could work, and rethink plans when the exact items they wanted were unavailable. Resource development therefore became a practical design process shaped by availability, substitution, and improvisation.

> *"Yes, at first I could not find the right size cans and tins I was searching for. But then I asked around my family and luckily one of them had the correct size." (0607993LAM)*

> *"It sometimes was even quite difficult to locate the exact type of recyclable material we were looking for in the quantity we needed. For instance, group members and learners were encouraged to collect materials over a period of time, while thinking of innovative substitutes for a certain material if that particular type was not available." (1010253MAK)*

Rather than describing these limitations only as obstacles, participants also showed how the search for materials pushed them to use what was available more creatively.

5.1.3. Sub-Theme: Using What Is Available Resourcefully

Improvisation is a teaching strategy through which educators create and use materials that are readily available in the local environment [26]. In the reflections, limited resources did not remain only a problem to be overcome. Participants began to describe recyclable materials as something that could be used purposefully, at low cost, and with greater teacher initiative. In this way, making LTSM became linked to a growing sense of pedagogical agency.

> *"I have realized that as a teacher I don't have to rely on the DBE to provide LTSM I can simply create it using the simplest items at no cost to facilitate effective teaching and learning." (1222068NGW)*

> *"I realized that there is absolutely no excuse to not have materials for teaching and learning. You can always make use of recyclable materials and create something amazing that the children can learn from." (0118637VAN)*

5.2. Theme 2: Collaboration as Idea-Sharing, Learning, and Problem-Solving

A second theme was the importance of collaboration. Participants did not describe group work merely as a task requirement, but as a space where ideas were shared, improved, and brought to life, where peers supported one another, and where problems were worked through together.

5.2.1. Sub-Theme: Sharing Ideas and Improving LTSM Together

A variety of points of view can lead to more creative solutions and strengthen analytical thinking [27]. Participants repeatedly described the group as a space where different ideas could be shared, corrected, enhanced, and developed further. Collaboration, therefore, functioned as a process through which stronger and more imaginative teaching materials were produced.

> *"Everyone came up with different ideas and thoughts for the project Creativity came easy because we also corrected and enhanced each other's ideas." (1101275MTO)*

> *"Every member had an idea of what they wanted to do. As soon as we started talking together and figuring out what we wanted to do, more and more ideas came to life." (1512367VAN)*

In addition to improving the materials, this collaborative setting also shaped how participants understood learning itself. They began to describe self-directed learning not as working alone, but as learning that can still involve peers.

5.2.2. Sub-Theme: Seeing Self-Directed Learning as Supported by Peers

Collaboration can work productively alongside self-directed learning [28]. Participants associated self-directed learning not only with individual effort, but also with knowing when to seek help, listen to peers, and recognise that useful knowledge is not held only by the lecturer. This suggests that collaboration did not weaken independence but helped participants understand self-directed learning as both personal and socially supported.

> *"That the teacher/lecturer is not the only person with the relevant knowledge and sometimes you understand things better from your peers." (1031085NON)*

> *"The collaborative learning experience highlighted the importance of interdependence and peer support in self-directed learning. It showed that self-directed learning is not just about working independently but also about seeking input, sharing knowledge, and learning from others." (0412673VOR)*

This understanding of learning as self-directed yet supported by peers also shaped how participants approached challenges, so problem-solving became a shared process of discussion, justification, and collective decision-making.

5.2.3. Sub-Theme: Collective Problem-Solving

Engaging in collaborative, solution-focused problem-solving requires moving away from analysing problems toward jointly constructing solutions [29]. Participants described problem-solving as working through disagreements, comparing options, and justifying decisions together. Problem-solving was thus not perceived as an individual activity, but as a process refined through dialogue and collective reasoning.

> *"The experience probably reinforced the value of collaboration in problem-solving, making me more inclined to seek input and work with others to find solutions in the future." (0303652NOM)*

> *"Working collaboratively greatly enhanced my critical thinking skills by exposing me to diverse perspectives and ideas. When engaging with team members from various backgrounds and expertise, I learned to approach problems from multiple angles. This broadened my understanding and encouraged me to consider solutions I might not have thought of on my own. Collaborative discussions often led to deeper analysis of issues, as brainstorming sessions required us to justify our ideas and challenge assumptions. For example, when we encountered a roadblock in our project, gathering input from different stakeholders helped us identify underlying factors that contributed to the challenge. This collective problem-solving process pushed me to think critically about our strategies and assumptions." (MMDD123123)*

5.3. Theme 3: Designing with Learner and Community Realities in Mind

A third theme was an increased awareness of context. Participants became more attentive to the realities of under-resourced schools and to the importance of creating materials that were easy to find, relatable, usable, and connected to learners' daily lives.

5.3.1. Sub-Theme: Becoming Aware of Under-Resourced School Realities

An equitable curriculum must attend to the lives of those who are marginalised [30]. In the reflections, awareness of LTSM shortages was not expressed only as a technical issue. Participants also described these shortages in relation to fairness, access, and concern for learners in under-resourced schools. The project was therefore increasingly understood in relation to educational inequality and responsibility.

> *"Learning about how teachers from under resourced schools struggle, and how learners are unable to learn what learners in resourced schools really broke me to a point whereby I thought I should be involved in this project that could help save someone else's future." (0508359TAF)*

> *"Working with the community helped me see how LTSM can link what learners learn in class to real-life situations, making lessons more relevant and meaningful." (1204590KEN)*

This growing awareness of school and community realities shaped how participants engaged in the design process, so they developed materials that were not only low-cost but also meaningful and relevant to the learners they had in mind. For example, in the Economic and Management Sciences and Business Studies context, examples of recyclable LTSM included cardboard-based business cycle diagrams, recycled-paper market-flow charts, bottle-cap sorting activities for needs and wants, cardboard cash-flow templates, posters on entrepreneurship concepts, and board games simulating trading, budgeting, or decision-making activities.

5.3.2. Sub-Theme: Creating Materials That Are Easy to Find and Relatable

Effective learning materials must be usable, contextually relevant, and responsive to the real conditions under which teachers and learners work, so their design must consider the realities of under-resourced settings [8]. Participants reflected carefully on whether the materials they used would be easy to find in the community and whether the finished resources would feel relatable in everyday life.

> *"I have to think twice before starting to make my project, because I needed to be sure that the type of recyclable product that I used would be easy to find in the community." (0406398DIA)*

> *"When creating the projects, what we had in mind was if the tools were relatable and tried to ensure that they fit with what we deal with in our daily lives." (0828108MSI)*

Participants also recognised that relevant materials could not be designed in isolation, so community input and involvement became important to the development of meaningful and context-sensitive LTSM.

5.3.3. Sub-Theme: Treating the Community as a Partner in LTSM Development

Community involvement aims at working together with rather than working for communities [31]. Participants described the community not only as the setting within which schooling takes place, but also as a practical source of recyclable materials, local knowledge, and support for creating LTSM. In this sense, LTSM development was imagined as a collaborative process that could extend beyond the classroom.

> *"Community is very important because these recyclable materials can be asked from them by the schools as donations and community members can volunteer to help create these teaching resources using the recycled materials to help phase out the issue of inadequate resources in our disadvantaged schools." (0319353ZUL)*

> *"Communities will increasingly play an active role in the design and development of LTSM. This collaborative approach can lead to resources that truly reflect local contexts, cultures, and languages." (0705882ZIK)*

5.4. Theme 4: Growing Critical Thinking and Adaptive Problem-Solving

A fourth theme was the growth of critical thinking and problem-solving. Participants described having to analyse practical problems, test possible solutions, and respond flexibly when initial ideas did not work.

5.4.1. Sub-Theme: Tackling Practical Design Challenges

Working with ordinary or improvised materials exposes students to issues of fragility, stability, and collapse, requiring them to solve problems as they arise rather than relying only on preconceived abstract plans [32]. Participants had to deal with fragility, durability, and structural problems while working with limited materials. Their responses suggest that reasoning was developed through hands-on problem-solving rather than through abstract planning alone.

> *"During the project, we struggled to create a durable visual aid using only cardboard and paper. I used critical thinking by suggesting we reinforce the cardboard with layered newspaper and tape, making it sturdy enough to hold additional elements." (0621779MAP)*

> *"In my poster, we had to glue the top piece, but the glue was not sticking. I had to think of something else that wasn't in the classroom to hold the poster up from the board. I then used sellotape, it was perfect." (0728865WAT)*

Addressing physical and structural problems was only one dimension of critical thinking, so participants also had to consider and balance differing ideas and viewpoints before arriving at a collective answer.

5.4.2. Sub-Theme: Thinking Through Multiple Perspectives

Diverse perspectives can generate more innovative ideas and enhance critical thinking [27]. Participants described weighing different ideas, justifying choices, and comparing alternatives before settling on a final design. This points to a form of reasoning strengthened through dialogue and evaluation.

> *"Working collaboratively exposed me to diverse perspectives, which enhanced my critical thinking skills. Team discussions allowed me to consider viewpoints I hadn't initially thought of and encouraged me to question assumptions. Collaboration pushed me to defend my ideas and justify decisions, which refined my reasoning and problem-solving*

approaches. It also helped me develop the ability to synthesize multiple ideas into a cohesive solution, improving both the depth and breadth of my critical thinking." (0907178MAY)

"Working collaboratively on the LTSM project enhanced my critical thinking skills by exposing me to diverse perspectives, forcing me to consider alternative solutions and evaluate evidence from multiple sources." (0617225MAB)

Looking at problems from multiple perspectives improved cognitive flexibility, making participants more willing to abandon their initial ideas, try alternative options, and adjust their strategies when needed.

5.4.3. Sub-Theme: Enhancing Problem-Solving Flexibility

Adaptive problem-solving refers to the ability to adapt rapidly and flexibly to new and changing circumstances as new challenges or information arise [33]. Participants reported less rigid thinking and a greater openness to exploring different options before deciding on a course of action.

"It helped me with thinking very critically and try to find as many solutions as possible rather than creating a problem for every solution because of fear that it might sound dumb." (0923643BLO)

"It has changed my problem solving approach by making me to have alternative solutions rather than one solution and to brainstorm and test all my solutions before choosing the right one." (1025114NDL)

5.5. Theme 5: From Task Requirement to Broader Educational Purpose

The final theme was a shift in motivation and purpose. For many participants, the project moved beyond a course task and came to be understood in relation to learner support, educational equity, open education, and future contribution.

5.5.1. Sub-Theme: From a Course Task to Meaningful Impact

Relevance refers to a connection that feels personally meaningful to the individual [34]. Participants described the project as something that became more meaningful as it progressed. Their reflections emphasised accessible resources, usefulness for others, and the impact the materials could have on learners. The task was therefore understood not only as something to complete, but as something with a broader educational purpose.

"I was motivated by the opportunity to create accessible resources for learners, and as the project progressed, I became even more passionate about the potential impact of Open Education on equality." (0303566MAA)

"I was initially motivated by the chance to make a positive impact and create useful learning resources for those with limited access. As the project progressed and I saw how our materials truly helped others, my motivation grew stronger. It shifted from being just a task to a meaningful way to support education and contribute to a greater cause." (0323816VAN)

As the project took on deeper personal meaning, participants also revisited their understanding of open education, coming to see it not just as free access to resources but as a broader practice grounded in sharing, inclusivity, and the common good.

5.5.2. Sub-Theme: Seeing Open Education as Equity, Collaboration, and Sharing

Open education is more than free resources; it involves approaches that promote participation, collaboration, and open knowledge sharing for the common good [35]. During the project, participants' views broadened. Instead of understanding open education mainly as

free access, they increasingly described it in terms of equity, collaboration, inclusion, and the ongoing improvement of resources.

> *"The LTSM project has deepened my understanding of open education, highlighting its potential to transform education through inclusive, collaborative, and sustainable practices." (0721957NKO)*

> *"Before the project, I saw Open Education primarily as a way to share free resources. After the project, my perspective expanded—I now view it as a powerful tool for equity and collaboration, enabling continuous improvement of materials through global contributions and fostering more inclusive, learner-centered education." (0901316HUA)*

This broader understanding of Open Education extended beyond the project itself, so participants developed a lasting sense of responsibility and an authentic motivation to integrate these values into their future professional paths.

5.5.3. Sub-Theme: Willingness to Contribute in the Future

Engagement in open educational practices can shape the long-term professional identities of educators, affecting how they envision their future roles as open and collaborative professionals [35]. Participants did not view the initiative as ending with the assignment. Instead, they saw it as influencing how they imagined their future professional engagement in open and equitable education. The impact of the experience thus seems to have extended beyond the immediate classroom task.

> *"I'd really like to participate on more open education in future because I really enjoyed doing this project and I got to express my creative side and learnt a lot with collaboration." (1225407MAF)*

> *"I will participate more on such projects because I learned lot from different people and I now know that I am capable of being creative and changing lives if learners in need of materials." (0519874LEB)*

6. Discussion: Managing Sustainability in Education

6.1. Circular Use of Recyclable Materials as a Catalyst for Learner Autonomy ('E')

The findings suggest that the requirement to design LTSM from recyclable materials functioned as an important catalyst for learner autonomy, particularly in relation to self-management within Garrison's [10] SDL framework. Across Theme 1, participants moved from seeing the task as "impossible" or unsuitable for the classroom to actively searching for materials, reconsidering what could be used, and making something from what was available. This interpretation aligns with Knowles' [9] view that self-direction involves identifying needs, locating resources, and taking initiative in the learning process. The project, therefore, did not treat sustainability only as an abstract principle [19,20]. It required participants to work with circular practices in concrete ways. In this regard, limited materials did not function only as a constraint but also as a condition that prompted teacher initiative and greater resourcefulness in under-resourced contexts.

6.2. Social Equity Through Collaborative Creativity ('S')

The social dimension of the project emerged not only through collaboration but also through increased awareness of learners' needs and community context. Themes 2 and 3 show that participants did not experience collaboration merely as group work. Rather, they described it as sharing and improving ideas, learning from peers, and solving problems together. In this regard, collaboration was part of how participants came to understand both the task and their own learning. The data also show that participants became more

attentive to the realities of under-resourced schools and to the need for materials that were easy to find, relatable, and relevant to learners' daily lives.

These findings resonate with the aims of SDG 4 and SDG 10 [2] because participants increasingly linked the project to educational access, fairness, and social responsibility. The project therefore drew attention not only to collaboration itself, but also to the wider social conditions to which the materials were expected to respond. In this way, collaborative creativity supported not only the production of stronger LTSM but also a more developed awareness of educational inclusion and the teacher's role within marginalised communities.

6.3. Open Education and Educational Responsibility (The 'G')

The governance dimension of the study is most clearly reflected in the changing understanding participants developed of open education and in their stated willingness to contribute to similar initiatives in the future. Theme 5 shows that participants moved beyond understanding open education only as the provision of free resources and began to describe it more in terms of collaboration, inclusion, equity, and shared improvement of materials. In this regard, the shift is consistent with the Recommendation on Open Educational Resources [8] and with scholarship on open pedagogy [17,18]. However, the findings support this argument mainly at the level of changing perceptions, motivation, and professional orientation rather than direct evidence of formal open licensing or public dissemination.

The data show that the project encouraged participants to see themselves as potential contributors to broader educational sharing and collaboration. Therefore, a stronger sense of pedagogical responsibility related to openness, equity, and future participation emerged. The value of the project lies not only in what participants came to understand about open education in principle, but also in how they began to position themselves in relation to what such openness may require of them as future teachers.

6.4. Critical Thinking and Adaptive Problem-Solving in the Nexus

An important contribution of the findings is that critical thinking and adaptive problem-solving did not emerge as peripheral outcomes, but as central features of the project experience. Theme 4 shows that participants had to respond to fragility, durability, and design failure by testing alternatives, revising assumptions, and weighing different viewpoints before selecting workable solutions. Such reasoning was not separate from the task; it formed part of how participants engaged with the practical demands of the project. These forms of reasoning were strengthened through hands-on making as well as through dialogue with peers, rather than through individual effort alone.

When read together with Themes 1 and 2, the data suggest that self-directed learning in this context was not only about independent initiative, but also about adaptive judgement exercised within collaborative and materially constrained conditions. Self-directed learning should therefore not be understood here in a narrow sense as working alone, but rather as initiative, judgement, and action developed through interaction, limitation, and practical problem-solving. In the same way, the project required participants not only to take initiative but also to revise, adapt, and respond to materials, peers, and emerging challenges. This strengthens the argument that the OER-ESG-SDL nexus is pedagogically significant because it brings sustainability, collaboration, and critical engagement together in practice.

7. Conclusions, Limitations, and Future Research

7.1. Conclusions

This study addressed the dual challenge of resource scarcity in South African schools [5] and the need for more sustainable and context-responsive approaches to LTSM

development. The findings show that when student teachers are required to design LTSM using recyclable materials [7], they develop greater resourcefulness, pedagogical agency, and responsiveness to local constraints. Collaboration supported idea-sharing, collective problem-solving, and a more socially grounded understanding of self-directed learning [10]. Engagement with under-resourced communities deepened participants' awareness of equity, accessibility, and relevance [2], while the project also broadened their understanding of open education as a practice of sharing, collaboration, and future contribution [8]. Taken together, the findings suggest that integrating circular material practices, collaborative creativity, and open education values into teacher education can help prepare future educators to create meaningful learning resources in more sustainable, equitable, and context-sensitive ways.

7.2. Limitations

This study is qualitative, phenomenological, and context-specific in nature, and for this reason, the findings are not statistically generalisable to all educational settings [21,22]. The study was conducted with a small sample of student teachers within one South African university context. Therefore, the results should be interpreted as situated and exploratory rather than as findings that may be extended broadly to all contexts in a general sense. In this regard, the value of the study lies in the depth of understanding that it provides within a particular setting rather than in statistical representativeness.

In addition, the study relies on participant reflections, which means that it captures perceived learning, meaning-making, and professional orientation rather than direct observation of classroom implementation or measured learner outcomes. Therefore, the findings should be understood in relation to what participants experienced, reflected on, and reported, and not as direct evidence of what may occur in every classroom context. While credibility was strengthened through an audit trail [22,23], the findings remain interpretive and bounded by the specific context in which the project took place. For this reason, the study should be understood as offering contextual and interpretive insights, while also being limited by the particular setting, sample, and nature of the data on which it is based.

Another limitation of the study is that it used critical reflections that were part of a course project. While these offered rich qualitative information about the participants' experiences, it is possible that some participants may have shaped their responses in ways they felt were academically acceptable or in line with lecturer expectations. As such, the results should be viewed as reflective accounts of perceived learning and meaning making, rather than direct evidence of classroom practice and learner outcomes. To improve trustworthiness, future studies could employ other sources of data, such as semi-structured interview data, classroom observations and learner feedback.

7.3. Future Research

Future research should investigate how similar LTSM projects based on recyclable materials and community-driven OER initiatives function in actual school settings, including the ways in which they may influence learner engagement, understanding, and self-directed learning [6]. This is important because the present study does not yet show fully how such initiatives may operate once they are enacted within school contexts where the realities of teaching and learning may differ from those within the project itself. Therefore, further research is needed not only to examine whether such materials can be implemented in practice, but also how they may shape teaching and learning in actual educational settings.

Mixed-methods and longitudinal studies would also be valuable in examining whether the shifts reported here in resourcefulness, collaboration, critical thinking, and openness are sustained over time and whether such shifts are transferred into professional teaching

practice. In this regard, it is not enough only to identify that these shifts may occur during the project itself. It is also important to determine whether such shifts remain visible over time and whether they continue once student teachers move into broader professional contexts. Therefore, future research should not only focus on immediate outcomes, but also on whether those outcomes remain meaningful beyond the duration of the study and are carried forward into later practice.

In addition, further empirical work is needed on the processes of digitising, sharing, licensing, and reusing such materials in order to understand how grassroots OER initiatives can be supported and scaled in under-resourced educational contexts [3,8]. These processes are important because the value of community-driven OER does not only lie in the creation of the materials themselves, but also in how such materials may continue to circulate, be reused, and remain accessible over time. Research that examines both the educational value and the environmental implications of these practices would therefore make an important contribution to the emerging literature on sustainability in teacher education. In the same way, such research may also assist in showing how sustainability, educational access, and innovation may be brought together more meaningfully in contexts where resources remain limited.

The role of community participation, future research and school-based projects should also investigate more formal ways to sustain relationships between schools and the community. These could include the creation of school-based collection points for recyclable materials, development of community recycling drives, collaboration with local businesses and recycling facilities, active involvement of parents and volunteers in the development of LTSM and school-based guidelines for the safe collection, storage, and use of recyclable materials in the classroom. Such approaches may help to increase the quantity of materials available and draw on local expertise while increasing community ownership of educational resources.

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References

1. Abulibdeh, A. Towards zero-carbon, resilient, and community-integrated smart schools and campuses: A review. *World Dev. Sustain.* **2024**, *5*, 100193. [CrossRef]
2. United Nations. *Transforming Our World: The 2030 Agenda for Sustainable Development*; United Nations: New York, NY, USA, 2015.

3. Hilton, J. Open educational resources and college textbook choices: A review of research on efficacy and perceptions. *Educ. Technol. Res. Dev.* **2016**, *64*, 573–590. [CrossRef]
4. Bliss, T.J.; Robinson, T.J.; Hilton, J.; Wiley, D.A. An OER COUP: College teacher and student perceptions of open educational resources. *J. Interact. Media Educ.* **2013**, *2013*, 4. [CrossRef]
5. Netshidzivhani, M.V.; Molaudzi, A.M. Assessing the correlation between school resource utilization and learners' success in South African public education: A case of Limpopo Province. *Int. J. Soc. Sci. Res. Rev.* **2024**, *7*, 77–90.
6. Chowdhury, P.; Rankhumise, M.P. Comparison of chemistry test performances between learners studying in resourced and under resourced schools. *J. Turk. Sci. Educ.* **2022**, *19*, 1254–1266. [CrossRef]
7. Wati, M.; Sutiniasih, N.; Misbah, S.; Mahtari, S. Annur, and Mastuang, Developing of physics teaching materials based on authentic learning to train problem-solving skills. *J. Phys. Conf. Ser.* **2020**, *1567*, 032084. [CrossRef]
8. UNESCO. *Recommendation on Open Educational Resources (OER)*; UNESCO: Paris, France, 2019.
9. Knowles, M.S. *Self-Directed Learning: A Guide for Learners and Teachers*; Association Press: New York, NY, USA, 1975.
10. Garrison, D.R. Self-directed learning: Toward a comprehensive model. *Adult Educ. Q.* **1997**, *48*, 18–33. [CrossRef]
11. Hodgkinson-Williams, C.; Arinto, P.B. (Eds.) *Adoption and Impact of OER in the Global South*; African Minds: Cape Town, South Africa; International Development Research Centre: Cape Town, South Africa; Research on Open Educational Resources for Development: Cape Town, South Africa, 2017.
12. Van Der Berg, G.; Du Toit-Brits, C. Adoption and development of OERs and practices for self-directed learning: A South African perspective. *Teach. Educ. Through Flex. Learn. Afr. (TETFLE)* **2023**, *4*, 1–25. [CrossRef]
13. Kirchherr, J.; Piscicelli, L. Towards an education for the circular economy (ECE): Five teaching principles and a case study. *Resour. Conserv. Recycl.* **2019**, *150*, 104406. [CrossRef]
14. Meria, L.; Bangun, C.S.; Edwards, J. Exploring sustainable strategies for education through the adoption of digital circular economy principles. *Int. Trans. Educ. Technol.* **2024**, *3*, 62–71. [CrossRef]
15. Zimmerman, B.J. Becoming a self-regulated learner: An overview. *Theory Into Pract.* **2002**, *41*, 64–70. [CrossRef] [PubMed]
16. Tough, A. *The Adult's Learning Projects: A Fresh Approach to Theory and Practice in Adult Learning*, 2nd ed.; Ontario Institute for Studies in Education: Toronto, ON, Canada, 1979.
17. Wiley, D.; Hilton, J.L. Defining OER-enabled pedagogy. *Int. Rev. Res. Open Distrib. Learn.* **2018**, *19*, 133–147. [CrossRef]
18. DeRosa, R.; Jhangiani, R. Open Pedagogy. In *A Guide to Making Open Textbooks with Students*; Mays, E., Ed.; Rebus Community: Montreal, QC, Canada, 2017; pp. 7–20.
19. Sterling, S.; Maxey, L.; Luna, H. (Eds.) *The Sustainable University: Progress and Prospects*; Routledge: Abingdon, UK, 2013.
20. Tilbury, D. *Education for Sustainable Development: An Expert Review of Processes and Learning*; UNESCO: Paris, France, 2011.
21. Braun, V.; Clarke, V. Using thematic analysis in psychology. *Qual. Res. Psychol.* **2006**, *3*, 77–101. [CrossRef]
22. Lincoln, Y.S.; Guba, E.G. *Naturalistic Inquiry*; Sage Publications: Beverly Hills, CA, USA, 1985.
23. Morrow, S.L. Quality and trustworthiness in qualitative research in counseling psychology. *J. Couns. Psychol.* **2005**, *52*, 250–260. [CrossRef]
24. Ramaila, S.; Zondi, S.M.; Mavuru, L. Pedagogical strategies employed by teachers in township schools for teaching meiosis and genetics with improvised resources. *J. Teach. Learn.* **2025**, *19*, 236–260. [CrossRef]
25. Ramaila, S. The use of improvised resources in science classrooms in South African township schools. *Educ. New Dev.* **2022**, *2022*, 367–370. [CrossRef]
26. Bhukuvhani, C.; Kusure, L.; Munodawafa, V.; Sana, A.; Gwizangwe, I. Pre-service teachers' use of improvised and virtual laboratory experimentation in science teaching. *Int. J. Educ. Dev. Using Inf. Commun. Technol.* **2010**, *6*, 27–38.
27. Plaisance, K.S.; Logel, C.; Lok, C. Making collaboration work: Fostering positive experiences and attitudes around psychological safety, diversity, and the value of teamwork. *Can. J. Scholarsh. Teach. Learn.* **2024**, *15*, 12. [CrossRef]
28. Buitrago, A.G. Collaborative and self-directed learning strategies to promote fluent EFL speakers. *Engl. Lang. Teach.* **2017**, *10*, 139–157. [CrossRef]
29. Xu, E.; Wang, W.; Wang, Q. The effectiveness of collaborative problem solving in promoting students' critical thinking: A meta-analysis based on empirical literature. *Humanit. Soc. Sci. Commun.* **2023**, *10*, 16. [CrossRef]
30. Banks, J.A. Multicultural education: Historical development, dimensions, and practice. *Rev. Res. Educ.* **1993**, *19*, 3–49.
31. Visser, M.W.; Pittens, C.A.; de Vries, R.; Zweekhorst, M.B. Community involvement in course-based higher education activities: Exploring its definition, guiding principles, and strategies—A narrative review. *J. High. Educ. Outreach Engagem.* **2023**, *27*, 59–80.
32. Davis, R.L.; Schneider, B.; Rosenbaum, L.F.; Blikstein, P. Hands-on tasks make learning visible: A learning analytics lens on the development of mechanistic problem-solving expertise in makerspaces. *Educ. Technol. Res. Dev.* **2024**, *72*, 109–132. [CrossRef]
33. Greiff, S.; Scheiter, K.; Scherer, R.; Borgonovi, F.; Britt, A.; Graesser, A.; Kitajima, M.; Rouet, J.-F. *Adaptive Problem Solving: Moving Towards a New Assessment Domain in the Second Cycle of PIAAC*; OECD Education Working Papers, No. 156; OECD Publishing: Paris, France, 2017. [CrossRef]

34. Priniski, S.J.; Hecht, C.A.; Harackiewicz, J.M. Making learning personally meaningful: A new framework for relevance research. *J. Exp. Educ.* **2018**, *86*, 11–29. [CrossRef] [PubMed]
35. Cronin, C. Openness and praxis: Exploring the use of open educational practices in higher education. *Int. Rev. Res. Open Distrib. Learn.* **2017**, *18*, 15–34. [CrossRef]

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