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Teachers', Researchers', and Educators' Partnerships: The Effect of Co-Creation on Pupils' Problem-Solving Performance in Mathematics

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Abstract: The collaboration between teachers, researchers, and educators has proven essential in advancing teacher professional development and improving pupils' outcomes. This study investigates the effect of co-creating instructional materials and lesson plans on pupils' mathematics problem-solving skills by employing the principles of co-creation and design-based research (DBR) to collect and analyze quantitative and qualitative data, providing a comprehensive understanding of the outcomes. A sample of 530 pupils from six primary schools was used, and data were collected using problem assessment sheets for primary 1, 2, and 3 pupils. The assessment tools measured pupils' problem-solving understanding and competencies across numbers and algebra, measurement and geometry, and data strands. Descriptive and inferential statistical analyses were applied. The findings revealed that pupils' performance improved across all three strands due to the co-creation process, with the most significant improvements observed among female pupils and those from rural schools. The factorial ANOVA results showed a significant interaction effect between class level and school location in the geometry and measurement and data strands, with $F(2, 518) = 15.15$, $p < 0.001$, and $F(2, 518) = 12.28$, $p < 0.001$, respectively. However, the interaction effect of the three independent variables on pupils' performance in the numbers and algebra strand, $F(2, 518) = 1.073$, $p = 0.342$, was not significant. The study concludes that co-creation between teachers, researchers, and educators holds substantial potential for enhancing the teaching and learning of problem solving in schools and provides an excellent opportunity for teachers, educators, and researchers to harness their skills and competencies to improve mathematics teaching and learning.

Keywords: co-creation; design-based research; instructional materials; problem solving; performance

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1. Introduction

The economic value of education for both personal and national development is undeniable. Consequently, human capital development through education and training has become central to enhancing quality of life and addressing the increasingly intense global competitiveness among citizens [1]. Over the past three decades, ensuring quality education at all levels has emerged as a significant focus for educators and stakeholders in the education sector worldwide. Sustainable Development Goal (SDG) 4, which aims to achieve "inclusive and equitable quality education and promote lifelong learning opportunities for all" by 2030, has become a critical benchmark. With only about seven years remaining, the urgency to meet SDG 4 has intensified, particularly in improving students' foundational skills in mathematics and literacy at both national and international levels.

Learning poverty (every child should be in school and be able to read and understand an age-appropriate text by age 10) as a description of the poor foundational literacy and numeracy learning outcomes in low- and middle-income countries (LMICs) by UNESCO in 2019 is one of the ways of measuring students' learning competencies [2].

However, the emergence of the COVID-19 pandemic in 2020 complicated global efforts to reduce learning poverty in the world, especially in LMICs, and hence has affected the achievement of SDG 4. For example, recent statistics show that the learning poverty gap has increased from 53 percent to around 63 percent because of the pandemic, and the situation in sub-Saharan African countries is worse as compared to other countries, as most students were deprived of learning and schooling because of the pandemic [3]. This is also evident in other studies such as [4], which argued that the "median level of achievement in many developing countries equates to approximately the 5th percentile of the peers in OECD countries" (p. 1).

Previous reports, for example, ref. [5], have also shown that children in developing countries are not learning, acquiring, and achieving the sufficient literacy and mathematical competencies that they will need to compete globally. Studies have further indicated that fewer than 50 percent of grade six students in sub-Saharan Africa achieved a minimum competency level. SDG 4.7 has been adopted and contextualized into many educational systems, schools, and classrooms, with particular attention to [6] sustainability model competencies, including systems thinking and anticipatory, normative, strategic, critical thinking, self-awareness, and integrated problem-solving competencies (see Figure 1).

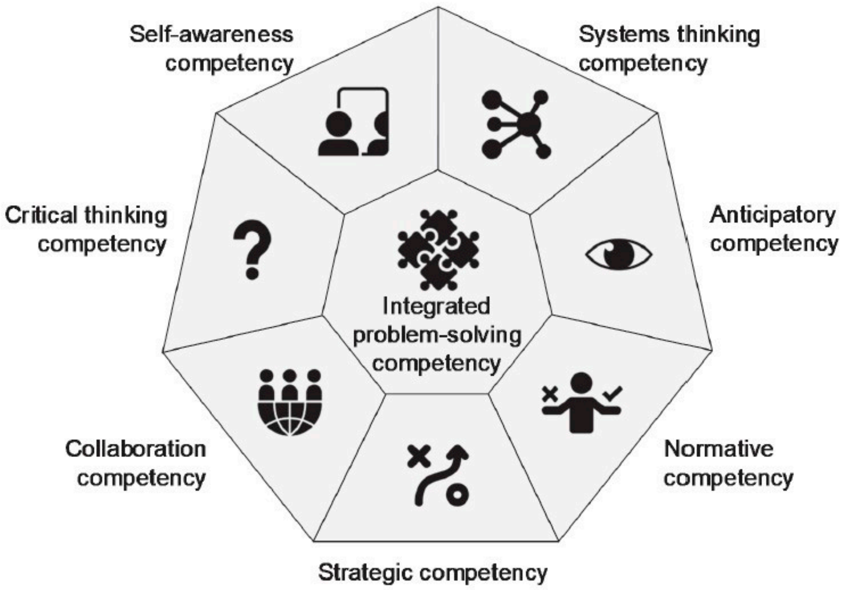

Figure 1. Key Competencies for Sustainability (UNESCO, 2017).

The importance of problem solving in mathematics education must be considered, as the field thrives on the processes of problem posing and problem solving. Numerous frameworks have been developed to understand better the problem-solving process and its contribution to students' comprehension. Consequently, many countries have incorporated problem solving into the national mathematics curricula to equip students with essential skills and techniques. Researchers have made many propositions as effective models to aid students in problem solving; heuristics is likely to be the standard method in problem solving based on the works of Pólya in the 1940s and serves as the foundation for many other models of problem solving [7]. The literature identifies several challenges related to students' difficulties in problem solving, with one of the primary issues being the misrepresentation of symbols and concepts in activities and assignments. Ref. [8] emphasized that enhancing students' mathematical communication skills can improve their problem-solving abilities.

Additionally, other researchers have argued that incorporating innovative teaching methods into problem-solving instruction often leads to better student performance. Ref. [9] proposed that mathematical reasoning, creativity, and communication are effective modern strategies for addressing the complex, unfamiliar, and non-routine (CUN) tasks crucial for developing mathematically literate and innovative societies. Ref. [7] also argued for a collaborative strategy that increases the mental capabilities of learners not as memorizers of mathematical concepts but as independent learners with adeptness in mathematical problem solving. They summed up this framework as mental agility, arguing that a problem solver must be self-motivated and inspired to take conscious actions relating to the content (concepts, connections, and procedures) through a psychological process.

Consequently, enhancing students' problem-solving abilities has become a significant focus in many classrooms, particularly STEM education, aligning with UNESCO's critical competencies for sustainability. The value of problem solving is extensively documented in the literature, leading numerous school curricula to emphasize its integration into daily lessons. For instance, the Ghanaian curriculum offers a comprehensive framework to advance learners' problem-solving skills and competencies. It articulates that "the curriculum is aimed at developing individuals to become mathematically literate, good problem solvers, can think creatively and possess the confidence and competence to participate fully in the affairs of the Ghanaian society as responsible local and global citizens" [10] (p. xiii).

Similarly, extensive research has been conducted on various methods and principles for incorporating problem solving into the teaching process, particularly in mathematics. However, it is essential to note that in Ghana, as in many other countries, students' performance on problem-solving questions in mathematics has been less than encouraging. For example, the performance of Ghanaian students in the Trends in International Mathematics and Science Study (TIMSS) in 2007 and 2011 demonstrated that, while their overall performance was poor across the three domains (knowledge, application, and reasoning), their scores in application and reasoning were significantly lower than those in knowledge-based questions [11,12]. Evidence suggests that teacher-designed tests often contain a minimal proportion of problem-solving questions [12,13].

Ref. [14] raised concerns that despite the efforts and contributions of educators, researchers, and policymakers to help students gain autonomy in mathematics problem solving, many learners still need help with understanding and taking responsibility for these tasks.

As discussed above, different emerging transformative and creative approaches to teaching and learning mathematics and problem solving have been documented and implemented in many mathematics classrooms [15]. However, most of these interventions are provided by mathematics education researchers and educators and are usually implemented by teachers in different classrooms. Research by [16] established that adapting or adopting these transformative and creative approaches has not yielded the expected results because of the heterogeneous nature of mathematics classrooms with learners from diverse backgrounds, abilities, and needs.

Ref. [17] argued for the need to provide more structure to strengthen communities of practice, highlighting the importance of deeper involvement in experimentation and the sharing of practices through co-creation among practitioners, researchers, and educators. Recent studies have emphasized the need to investigate interventions and professional development programs that utilize co-creation to enhance teachers' pedagogical, content, and professional knowledge. By co-creation, we refer to the collaborative process in which teachers, educators, and researchers collaborate to develop mathematics lesson plans and instructional resources for teaching mathematical concepts to students in grades 1–3. The present research aimed to explore the impact of co-creation on primary school pupils' mathematics problem-solving performance. The following research questions guided our study:

(a) What is the status of primary school pupils' mathematics problem-solving performance?
(b) How did co-creation affect primary school pupils' mathematics problem-solving performance?
(c) How do the effects of co-creation on primary school pupils' mathematics problem-solving performance vary across gender, school level, and school location?

2. Theoretical Framework

2.1. The Concept of Co-Creation

Co-creation is a pedagogical paradigm shift that emphasizes shared agency in knowledge construction. It is a dynamic and collaborative process where teachers and students work together to design, implement, and refine educational activities, content, and assessments. This approach transcends the traditional teacher-centric model and aligns with constructivist learning theories, emphasizing the learner's active role in constructing knowledge [18]. Co-creation positions learners as active participants in the learning process rather than passive recipients of specific or general information.

Co-creation is a collaborative and reciprocal process at its core. It involves all stakeholders—teachers, students, and often, external partners—in making a meaningful contribution to developing curriculum, learning experiences, and outcomes. This approach challenges the traditional teacher-centered model by involving pupils as active participants in their learning. Students are not just recipients of information but actively contribute to designing and implementing their educational experiences. This active participation fosters shared ownership of the academic experience and processes and enhances student engagement and learning outcomes [18,19].

The concept of co-creation has existed for decades and has roots in business and design, where it was initially used to describe collaborative innovation between companies and customers [20]. Over time, this concept was adapted to education, particularly within primary and higher education, to enhance student engagement and learning outcomes by actively involving them in course and curriculum design [21]. The growth of co-creation in education reflects broader pedagogical shifts toward student-centered learning, emphasizing autonomy, personalized learning experiences, and democratizing the classroom environment. They are deeply aligned with constructivist learning theories, particularly those influenced by Vygotsky's social constructivism, which argues that learning is a social process where knowledge is constructed through interaction [22].

Self-determination theory (SDT), designed by the framework of [23], also provides an extensive overview of the psychological basis for co-creation whereby the application of SDT represents creating a conducive educational environment that supports students' autonomy, competence, and relatedness, which in turn fosters intrinsic motivation and promotes more profound engagement with learning materials. In a practical situation, where students participate in the design of their learning experiences, it directly supports these psychological needs by allowing students to make meaningful choices (autonomy), engage in challenging but achievable tasks (competence), and collaborate in a supportive environment (relatedness). This heavily impacts students' competence-building skills while developing meaningful relationships with peers and teachers, enhancing motivation and engagement. Mathematics education has always struggled to engage pupils in meaningful and successful learning experiences. It is a complex subject in which traditional teaching approaches may fail to engage all pupils effectively.

With the clear demonstration that co-creation can significantly impact teaching practices and student learning, this concept shifts teachers' role from being the sole authority in the classroom to becoming facilitators of learning. This bold shift encourages more reflective and responsive teaching practices, as teachers must continuously adapt their methods based on student feedback and collaboration [18]. Teachers involved in co-creation often report increased professional development and job satisfaction as they gain deeper insights into their students' learning processes, patterns, and needs [19].

Co-creation has been found to improve student involvement, motivation, and academic success. Students who co-create their learning experiences are more likely to take ownership of their education, resulting in deeper learning and higher knowledge retention. This is especially true in mathematics education, where co-creation can benefit students' development of more critical problem-solving skills by involving them in designing activities and assessments that are meaningful and relevant to their experiences [24,25]. It is also crucial to mention that it helps students apply mathematical principles to real-world issues, improving their capacity to think critically and apply their knowledge in various contexts [26].

With the compelling benefits associated with co-creation in mathematics education, various challenges must be addressed to ensure its successful and effective implementation for the masses. A common challenge is ensuring equitable participation among students. In co-creation processes, there is a high risk that more vocal or confident students may dominate, while others may feel marginalized or less inclined to participate. Teachers must be equipped facilitators, ensuring that all students can contribute meaningfully to the co-creation process regardless of individual learning patterns or strategies [27]. Additionally, co-creation requires a significant investment of time and resources from teachers and students. Designing and refining co-created learning activities can be time-consuming and may be a barrier in contexts with rigid curricula or limited resources. However, it is essential to remember that the long-term benefits of increased student engagement and improved problem-solving skills may outweigh these initial challenges, making investing worthwhile.

2.2. Effect of Co-Creation on Teachers' Practices

The effect of co-creation on teachers' practices is a critical area of inquiry in contemporary educational research, particularly as education systems increasingly emphasize collaborative and participatory approaches, especially in mathematics education, and their ripple effects on pupils' performance. Co-creation primarily involves collaboration between teachers and students in designing and implementing aspects of the educational process. It significantly affects how teachers approach their roles, instructional methods, and student relationships.

One of the primary impacts of co-creation is the shift in traditional teacher–student dynamics. Teachers who engage in co-creation often move away from authoritative, top-down instructional methods toward more democratic and collaborative approaches. This shift fosters a more inclusive learning environment where pupils are active participants rather than passive recipients of knowledge and participate in making decisions related to knowledge acquisition. Co-creation fosters an environment of mutual respect and shared responsibility, which can lead to more meaningful student engagement. When students are actively involved in co-creating their learning experiences, they are more likely to be invested in the outcomes, which, in turn, positively influences their motivation and academic performance. For teachers, this engagement provides valuable insights into students' learning preferences and challenges, enabling them to tailor their instructional approaches more effectively [28].

The co-creation practices have been linked to improvements in teachers' reflective practices concerning collaborating with students in curriculum design and delivery; they are compelled to reflect more deeply on their teaching methods, learning objectives, and assessment strategies. This reflective process can lead to a more critical examination of existing practices and foster continuous professional development. Teachers who regularly engage in co-creation are more likely to experiment with innovative teaching techniques and adapt their practices based on direct feedback from students [13,19,29].

In addition to these pedagogical benefits, co-creation has been shown to affect teachers' professional satisfaction and well-being positively. The collaborative nature of co-creation has a high potential to reduce the feelings of isolation often experienced by educators, as it promotes a sense of community and shared purpose within the classroom. Teachers who participate in co-creation initiatives report greater job satisfaction and a stronger sense of connection to their students, which can mitigate the effects of burnout and professional fatigue and make them feel part of a larger educational community. Power imbalances between teachers and students can hinder genuine collaboration, and policymakers must address this issue. Careful consideration of managing these dynamics is needed to ensure that all voices are heard and valued. Also, the scalability of co-creation practices remains a topic of debate, particularly in larger educational institutions where such initiatives may be more challenging to implement effectively [30].

2.3. Effect of Co-Creation on Pupils' Learning and Performance

Mostly, students need more focus and resilience to excel in their academic pursuance when confronted with immediate environmental factors. Traditional mathematics instruction often fails to engage all students effectively, leading to a lack of interest and decreased performance. The most significant effect of co-creation on pupils' learning is enhancing engagement and motivation. This value is created by making learning more interactive and relevant to students' interests and experiences [18]. Including students in designing their learning activities makes them more likely to take ownership of their education, increasing their intrinsic motivation to learn [23].

The narrative of Ref. [19] showed that students who participate in co-created learning environments exhibit higher levels of engagement, which is crucial for deep learning and long-term knowledge retention. It is valuable for identifying and formulating basic and advanced formulas in the study of mathematics. In mathematics education, where engagement often predicts success, co-creation can be particularly effective. By allowing students to co-create problem-solving tasks, teachers can make mathematics more accessible and enjoyable, improving attitudes toward the subject and better academic performance [27]. This sense of accomplishment in co-creating learning activities can significantly boost students' confidence and motivation.

Developing problem-solving skills is a central goal of mathematics education at all levels. Empirical studies support the notion that co-creation enhances students' problem-solving abilities. Research by [28] found that students who participated in co-created mathematics activities demonstrated significantly improved problem-solving skills compared to those who followed traditional, teacher-led instruction. The study suggests that the active involvement of students in the learning process leads to a more profound comprehension of mathematical principles, as students are encouraged to explore different strategies and solutions collaboratively.

Mathematics is a non-ending educational journey for pupils, so developing critical thinking, problem-solving, and collaborative skills is paramount. As pupils co-create their learning environments, they learn to negotiate, communicate, and collaborate with peers and teachers. These skills benefit their immediate academic performance and are essential for long-term educational and professional success [21]. The iterative nature of co-creation, where pupils are encouraged to critically reflect on their learning experiences and provide feedback, propagates a deeper understanding of the subject and promotes continuous improvement.

Despite the numerous advantages of co-creation, research by [31,32] and others has shown that during the co-creation process, teachers and, for that matter, the partners in the co-creation process are required to make series of shifts and adjustments in the roles and autonomies to help facilitate the effective running of the process. Such adjustments and shifts usually bring about tensions between the different actors, which could affect the efficient running of the process. Research by [33] established that such partnerships could bring about intellectual, emotional, pedagogical, and professional tensions and discomforts. They added that the inability of the partners to manage these tensions could have an immense negative effect on the overall purpose of the partnership. Similarly, Ref. [31] in their study also established that one of the significant challenges during co-creation is managing the power dynamics that may exist. They argued that these power dynamics create conflict that manifests internally and interpersonally, and these balancing perspectives are usually tricky, particularly in the vertical power structure of classrooms.

2.4. The Effects of Teachers and Researchers' Partnerships on Students' Learning

Education is a continuous journey where learning and relearning are formative catalysts for long-term growth and development. Collaboration between teachers and researchers, often called "research–practice partnerships" (RPPs), profoundly impacts students' learning outcomes in a co-creation environment. These partnerships bridge the gap between academic research and classroom practice, creating a more evidence-based approach to teaching and learning. The teachers' and researchers' collaboration directly impacts the quality of teaching practices, contributing to evidence-based strategies and tools. In contrast, teachers provide contextual knowledge about their students and classroom dynamics. This combination allows for developing and implementing instructional methods that are both theoretically sound and practically applicable. Such partnerships often lead to the co-creation of innovative teaching materials and strategies that are more effective in addressing the diverse needs of students [32].

By grounding teaching practices in research, these partnerships help bridge the gap between theory and practice, making learning more relevant and impactful for pupils. Research by [34] also indicated that when teachers engage in research partnerships, they are more likely to adopt and sustain evidence-based practices in their classrooms, leading to increased student engagement and improved academic achievement. These collaborations allow for continuous professional development, where teachers learn new strategies for enhancing student learning and for better execution of these strategies effectively. As a result, students benefit from a more informed and reflective teaching approach, which contributes to better learning outcomes.

Teacher–researcher partnerships often lead to curriculum development informed by the latest educational research, trends, and needs. This ensures that the content and methods used in the classroom are up-to-date and aligned with best practices in education. When the curriculum is research-informed, students are more likely to engage with the material meaningfully, leading to deeper understanding and knowledge retention [35]. A research-informed curriculum can be more responsive to students' changing needs, allowing for adjustments based on ongoing research findings. These partnerships also empower teachers by involving them in the research process, allowing them to take on roles as co-researchers rather than just implementers of others' ideas. This empowerment also extends to students, who benefit from a more dynamic and responsive learning environment. When teachers feel more confident in their practices, they can create a more supportive and engaging learning atmosphere, positively impacting student learning [36].

It is worth noting that despite the positive effect of such partnerships on pupils' learning experiences and bridging the gap between theory and practice, the generative role of conflicts, pedagogical disagreements, teacher–research role dynamics, and inherent context-specific characteristics differences cannot be underestimated. For this reason, Ref. [31] argued that partners in the co-creation process ought to understand these tensions and use adaptive strategies to share power and responsibilities to help reshape the co-creation process. They argued that one of the essential ways of power sharing is through dialogues and an open-minded approach.

2.5. Conceptual and Theoretical Framework

Based on the objectives of the entire project, which aims to develop effective and innovative methodologies to enhance learners' problem-solving competencies and mathematical mindset, it is important to have a conceptual framework to help learners examine mathematical problems from a holistic perspective. One of the main concepts underpinning the project is systems thinking. For this purpose, the definition of the National Research Council [37] (pp. 63–64) was adopted. The ability to understand how an entire system works and how an action changing or one part of the system malfunctioning affects the rest of the system and adopt a big picture perspective on work includes judgment and decision making, system analysis, systems evaluation, and abstract reasoning about how the different elements of a work process interact.

The ability to understand and interpret complex problems is based on the individual learner's ability to develop a holistic picture of the situation and use this picture to provide an inductive analysis of the different parts of the problem. For this reason, it is important to create an environment where there will be opportunities for learners to bridge the gap between their informal and formal knowledge about the concept under consideration. To help learners fully improve their problem-solving competencies and mathematical mindset, researchers, educators, and teachers must collaborate and co-create context-specific mathematics lessons and resources. We thus adopted [38] the Systems Thinking Hierarchical (STH) model. This model is built on four levels of sequential growth: (1) identify the system components and processes; (2) identify relationships between separate components and identify dynamic relationships between the system components; (3) understand the cyclic nature of systems, organize components, place them within a network of relationships, and make generalizations; and (4) understand the hidden components of the system and the system evolution in time (prediction and retrospection). This conceptual framework is consistent with the theoretical underpinnings of the theory of change.

2.6. Theory of Change

The theory of change is a concept that has gained substantial recognition across multiple disciplines, particularly in program evaluation and development. Over the years, it has been a structured approach to understanding and articulating the pathways through which interventions are expected to lead to desired outcomes. It serves the purpose of delineating a strategic path through which a program aims to achieve its long-term objectives and generate significant impacts. It extends beyond a mere description of program activities and outcomes, emphasizing the systematic mapping of causal relationships linking these activities to the intended goals [39]. Generally, before any significant change can occur within an accepted structure or system, there is a need for a comprehensive illustration or justification of why the change is necessary and how it will be beneficial.

The concept has been examined from different perspectives. Ref. [40] defined it as explicitly articulating how and why a desired change is expected to happen in a particular context. Similarly, Ref. [41] defined it as "an ongoing process of discussion-based analysis and learning that produces powerful insights to support programme design, strategy, implementation, evaluation and impact assessment, communicated through diagrams and narratives which are updated at regular intervals" (p. 5). The present study adopts UNDG's [42] definition of the theory of change, which is "a method that explains how a given intervention, or set of interventions, is expected to lead to specific development change, drawing on a causal analysis based on available evidence" (p. 4). The goal is to identify solutions that effectively address the underlying causes of problems hindering progress and to provide guidance on the appropriate strategies to adopt. This is consistent with the assertion of [43] that studies should not just answer the question of what works but also how, where, for whom, and at what cost. This consideration includes the process's benefits, effectiveness, and feasibility. The present study thus utilized the theory of change, and its application process is illustrated in the conceptual framework depicted in Figure 2 below.

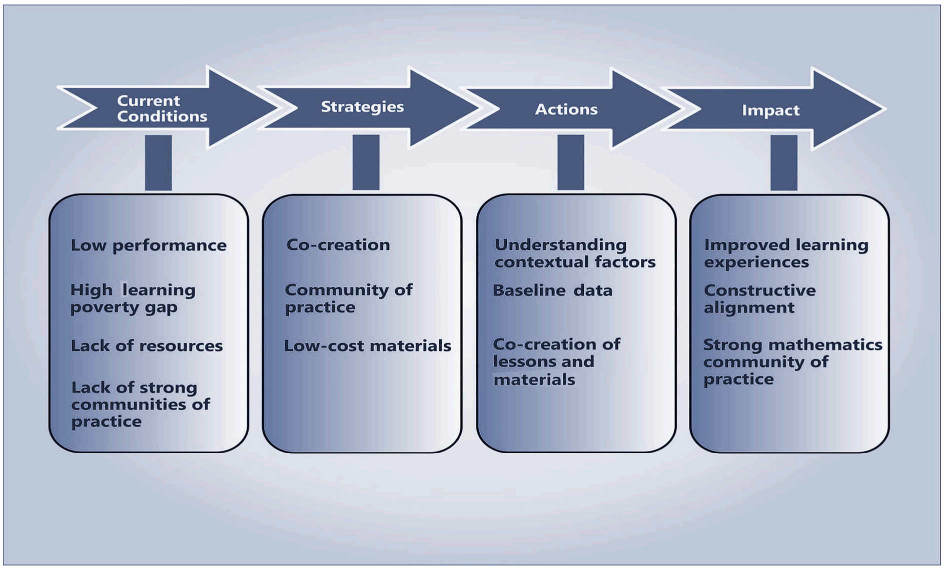

Figure 2. The Theory of Change.

3. Materials and Methods

As discussed above, the literature highlights numerous challenges students face in learning mathematics, with low problem-solving competencies being a significant concern. However, designing an effective intervention to address this issue requires an assessment of the local context to understand the problem's nature and create a context-specific solution. This project leverages the principles of co-creation and design-based research (DBR) by collecting and analyzing quantitative and qualitative data to understand the issue comprehensively. DBR is particularly suited for this study, given its focus on co-creation between researchers and practitioners (teachers). DBR is an approach that seeks to improve educational practices through the development of products, involving iterative cycles of design, testing, data collection, evaluation, redesign, and adoption [44,45].

The present study is structured in four phases (see Figure 3 below). The analysis and exploration stage aimed to analyze the practical problem from different contexts by collecting baseline data about pupils' problem-solving performance and perceptions. This was followed by the design and construction stage involving six schools, where the researchers and the practitioners met to discuss the results from stage 1 (baseline survey of pupils' problem-solving competence) and co-create lesson plans and instructional resources.

In phase two, researchers and teachers, through co-creation, developed an intervention (designing innovative lesson plans and instructional resources) to support the teaching of problem solving. Prior research suggested that co-creating these activities will help improve learners' problem-solving competencies [46] and provide a platform where teachers work together and learn from each other through communities of practice. The overarching goal of the co-creation process was to design context-specific lesson plans with challenging activities that could help bridge the gap between learners' informal and formal mathematical understanding. The co-creation process was carried out in three stages. During stage 1, teachers designed a sample lesson they would like to teach—this initiative aimed to foster teamwork among teachers from different schools who may not have worked together. The teachers developed sample lesson plans, which were reviewed and discussed with researchers and educators. These discussions focused on the rationale behind the selected topics, activities, and strategies for delivering the lessons in diverse classroom settings. An example of the teachers' prepared lesson plans is presented in Figure 4.

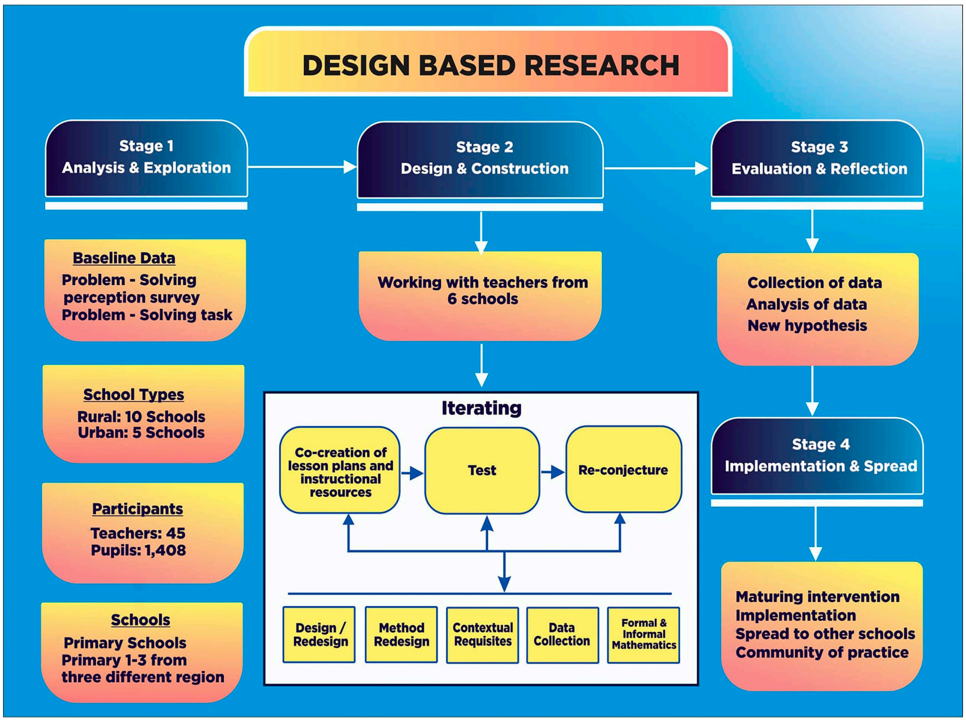

Figure 3. Design-Based Research.

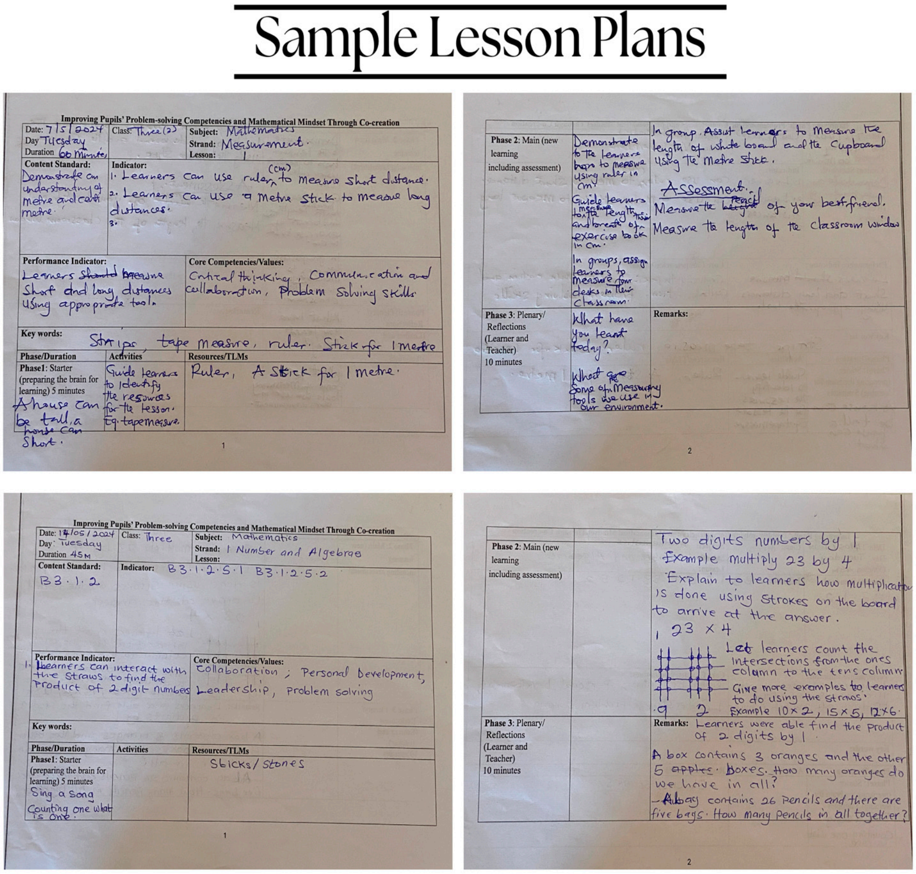

Figure 4. Sample Lesson Plans.

In stage 2, after reviewing the lesson plans developed by the teachers, the researchers and educators worked together to brainstorm the various components of the plans. During the discussions, we decided on the specific lessons to co-create, aligning them with the topics and strands the teachers would cover in the upcoming weeks. Tailored lesson plans were co-created for different classes. Figure 5 below is an example of the co-created lesson plan. During the discussions, it became evident that having teachers from urban and rural schools allowed for a more straightforward adaptation of the lessons to their respective contexts. This approach not only enhanced engagement but also addressed the unique needs and challenges of each setting.

Improving Pupils' Problem-solving Competencies and Mathematical Mindset Through Co-creation

Date: Day Duration	Class: B2	**Subject:** Mathematics **Strand:** Geometry and Measurement **Lesson:**
Content Standard: Describe and analyze 2D shapes and 3D objects.	**Indicator:** (B2.3.1.1.1) Identify the common features or attributes of 3D objects (spheres, cylinders, cones, pyramids, cubes) of different dimensions or orientations.	
Performance Indicator: Learners can identify 2D and 3D shapes and objects		**Core Competencies/Values:** Problem-solving, Critical thinking, collaboration, personal development, and leadership
Phase/Duration	**Activities**	**Resources/TLMs**
Phase1: Starter (preparing the brain for learning) 5 minutes	• learners sing songs,/recite poems to stimulate their interest • through talk for learning, learners mention the different shapes they know E.g. square, triangle, circle etc	• Real objects of 2D and 3D shapes and objects • 2D and 3D objects and shapes boldly drawn on manila cards 
Phase 2: Main (new learning including assessment)	• Through 'Talk for Learning', learners relate the shapes and objects mentioned in the starter to the ones they can see in the environment. • Displays real objects and 2D cut out shapes for learners to identify by sorting (triangles, squares, rectangles, circles) on the surfaces of 3D objects (cubes, cylinders, spheres, rectangular prisms) in the classroom or beyond. • Learners explain how the sorting was done, by discussing in groups the features or criteria used to sort them with the help of the teacher. • Learners describe the difference between two given pre-sorted sets of familiar 3D objects or 2D shapes and the feature or criteria used to sort them **Assessment:** When Ernest is on vacation, he sits under the hut below to rest. Study it carefully and draw all the shapes you can see in your workbook for marking. 	
Phase 3: Plenary/ Reflections (Learner and Teacher) 10 minutes	What have we learned today? Describe triangles, rectangles, circles, etc Independent Activity/Homework Look for shapes in the house and in your environment and sort them out.	**Remarks:**

Figure 5. Co-created lesson plan.

The teachers, educators, and researchers discussed and examined each section of the co-created lesson plans and decided how they could be delivered in different classroom contexts. In stage 3, the teachers piloted the co-created lesson plans. During the pilot, the educators and the researchers observed the lessons and had a reflection section with the teachers to discuss the challenges and the way forward. One of the significant challenges we anticipated was the role dynamics, as we predicted that the teachers would expect us to take the lead, and they would follow. We, however, demystified this by meeting the teachers and discussing with them the nature of the work we are doing, their role, and our role, providing assurance that we were not there to tell them what to do or how to do their work but to work together to support pupils' learning, creating a conducive atmosphere for collaboration. The data collected through observations and interviews were analyzed and used to make necessary adjustments to enhance the effectiveness of the intervention. The iterating process involved the design and redesign of the lesson plans and methods, with awareness of the contextual requisites of the students and the integration of formal and informal mathematics.

The data collection procedure for the entire project included baseline data collection, co-creation of lesson plans and instructional materials (after which the teachers implemented the co-created materials for eight weeks), and end-line data collection. The target population for this study included all teachers and pupils in primary grades 1–3. Six schools (two urban and four rural) were purposively selected for this project phase.

The two main criteria for choosing the schools and participants were school location (urban and rural) to assess the extent to which learners, particularly those from rural communities, could benefit from the intervention, and gender equity and social inclusion to ensure that all learners and schools had equal opportunities to participate. To maintain gender equity in the sample, especially among pupils, we selected an equal proportion of students in classes with imbalanced gender ratios (more males than females or vice versa) to complete the assessment tools. Five hundred and thirty (530) pupils from the six schools completed the baseline and end-line assessment tools, and their background characteristics are presented in Table 1.

Table 1. Demographic characteristics of participants.

		Number	Percentage (%)
Gender	Male	283	53.4
	Female	247	46.6
	Total	530	100
Class	Primary 1	158	29.8
	Primary 2	177	33.4
	Primary 3	195	36.8
	Total	530	100
School Location	Urban	280	52.8
	Rural	250	47.2
	Total	530	100

The data in Table 1 show that 283 (53.4%) of the pupils who completed the problem-solving assessments were male, and 247 (46.6%) were female. Regarding school location, 280 (52.8%) participants were from urban schools, while 250 (47.2%) were from rural schools. Despite having four rural schools and only two urban schools, the enrollment in urban schools exceeded that of rural schools, as shown in Table 1. The instrument used to collect the data presented in this study was a problem-solving assessment tool designed and piloted for primary 1–3 pupils. The questions were designed with cognizance of the content of the Ghanaian national curriculum and the use of standardized questions from the Mathematics Assessment Resource Service, which are relevant to the Ghanaian context. The problem-solving assessment tool was used to measure pupils' problem-solving competence, and each tool had five items measuring pupils' competence in numbers and algebra, geometry and measurement, and data. Each strand was scored out of five for uniformity and easy analysis. Table 2 below shows the distribution of questions for the different strands. The questions were piloted with 60 pupils (20 each from primary 1, primary 2, and primary 3). After the pilot, it was observed that the pupils had challenges with some of the terminologies used, so we revised the wording of the items after our discussions with some teachers who provided key and context-specific terminologies that could be used.

We began the data analysis by correcting all the assessment sheets and inputting the results into SPSS 27 (Statistical Package for Social Sciences). The data were meticulously cleaned to ensure the accuracy of each student's results. Five hundred and thirty-three (533) students completed the baseline assessment, while five hundred and thirty (530) students participated in the end-line assessment. To maintain consistency, the data from the three students who did not participate in the end-line assessment were excluded from the final analysis. Both descriptive (frequencies, percentages, and standard deviation) and inferential statistics (independent *t*-test and one-way and factorial ANOVA) were used to analyze the data from the baseline and end-line assessments.

Table 2. Distribution of questions by strand and Level.

Strands	Class/Level		
	Primary 1	**Primary 2**	**Primary 3**
Numbers and Algebra	Questions 1, 2, 5	Questions 1, 2, 4	Questions 1, 2, 3
Measurement and Geometry	Questions 3a, b, c, d, e	Questions 5a, b, c, d	Questions 5a, b
Data	Question 4	Questions 3a, b	Questions 4a, b, c, d

4. Results

4.1. Pupils' Performance by Strand

Table 3 illustrates a significant improvement in pupils' performance in the end-line assessment across all three strands. Specifically, pupils' overall performance in the number and algebra strand increased by 0.43 mean points, followed by 1.02 mean points for the data strand. The geometry and measurement strand saw the highest increase of 1.03 mean points. Pupils demonstrated substantial improvement in their mathematics performance, and this progress could be attributed to the fact that co-created lessons and activities enabled teachers to adopt a hands-on teaching approach that engaged pupils to use context-specific instructional materials to support the teaching and learning process.

Table 3. Pupils' performance by strand.

	Baseline Data Results			Endline Data Results					
Strands	**No.**	**Mean**	**SD**	**No.**	**Mean**	**SD**	**df**	**t**	***p***
Numbers and Algebra	530	2.62	1.34	530	3.05	1.41	528	5.09	<0.001
Geometry and Measurement	530	2.60	2.07	530	3.63	1.73	528	8.73	<0.001
Data	530	2.28	2.08	530	3.30	2.00	528	8.11	<0.001

$p < 0.05$.

4.2. Pupils' Problem-Solving Performance and Gender

In addition to the general results, a cross-case analysis was conducted to determine if there were significant differences in pupils' performance based on the independent variables (gender, school location, and grade level). The first analysis explored the relationship between gender and performance, and the results are displayed in Table 4.

Table 4. Independent *t*-test of Gender and Pupils' Performance.

	Baseline Data Results			Endline Data Results				
Strands	**Gender**	**Mean**	**SD**	**Mean**	**SD**	**df**	**t**	***p***
Numbers and Algebra	Male Female	2.63 2.60	1.38 1.32	3.11 2.98	1.36 1.47	528	1.24	0.22
Geometry and Measurement	Male Female	2.65 2.55	2.06 2.09	3.58 3.68	1.74 1.72	528	0.41	0.68
Data	Male Female	2.29 2.29	2.10 2.06	3.27 3.32	2.01 1.99	528	0.24	0.84

$p < 0.05$.

Table 4 shows no significant difference between pupils' performance and their gender, consistent with the findings from the baseline data. However, it is worth noting that a critical analysis of the descriptive statistics shows that both male and female pupils' performance improved across all three strands. The female pupils' performance increase was more significant in the geometry and measurement and data strands than their male counterparts. That is, female pupils outperformed their male counterparts in these strands. The male pupils' performance (a mean difference of 0.42) in the numbers and algebra strand improved more than that of their female counterparts. However, this was below the mean point increments of 1.24 and 1.04 in the female pupils' performance in questions measuring their competencies in geometry and measurement and data, respectively.

4.3. Pupils' Problem-Solving Performance and School Location

For this study, two locations (urban and rural) were used to classify the schools. There is a general perception that pupils from urban schools usually perform better than their counterparts from rural communities due to several factors, including but not limited to the availability of instructional resources, instructional quality, etc. In this section, we discuss how pupils' performances differed across urban and rural schools and if the co-created lessons, activities, and resources led to any improvement in pupils' performances. Table 5 below presents these results.

Table 5. Independent *t*-test of school location and pupils' performance.

	Baseline Data Results			Endline Data Results				
Strands	**School**	**Mean**	**SD**	**Mean**	**SD**	**df**	**t**	***p***
Numbers and Algebra	Urban Rural	2.76 2.51	1.30 1.38	3.13 2.97	1.30 1.53	528	2.79	0.004
Geometry and Measurement	Urban Rural	2.95 2.33	2.07 2.04	3.64 3.62	1.79 1.68	528	3.30	0.001
Data	Urban Rural	1.93 2.58	2.01 2.09	3.15 3.46	2.01 1.99	528	2.98	0.003

$p < 0.05$.

The results show a significant difference between pupils' performance and school location. Urban school pupils outperformed their rural counterparts in numbers and algebra and geometry and measurement. Further analysis also indicate that the performance of pupils from urban and rural schools improved across all three strands. However, it is worth noting that pupils from rural schools outperformed their counterparts in questions measuring their data collection and handling competencies. A critical analysis of the descriptive statistics also shows a mean increase of 0.46 and 1.31 for rural pupils in questions measuring their competencies in numbers and algebra as well as geometry and measurement strands, respectively, which is above that of their urban counterparts. The results confirm the initial assertion that pupils from urban schools usually perform better than their counterparts from rural schools. However, the observable improvement in the performance of rural school pupils across the three strands cannot be underestimated. We can argue that the co-created lessons and instructional materials positively impacted pupils' performance, especially those from rural schools.

4.4. Pupils' Problem-Solving Performance and Class Level

This section discusses the relationship between pupils' performance and their class. We wished to examine pupils' problem-solving performance across different class levels and see how this revealed variations. We used analysis of variance (ANOVA) to explore these differences. Table 6 below depicts the results of the study.

Table 6. One-way ANOVA of class and performance.

Strand		Sum of Squares	df	Mean Square	F	p
Numbers and Algebra	Between Groups Within Groups	64.26 2005.1	2 528	32.12 1.89	16.93	<0.001
Geometry and Measurement	Between Groups Within Groups	694.4 3448.8	2 528	347.20 3.26	106.41	<0.001
Data	Between Groups Within Groups	536.49 4145.33	2 528	268.24 3.92	68.40	<0.001

Table 6 above indicates a significant difference in pupils' performance across the different strands. The analysis reveals that primary 2 pupils outperformed their counterparts in questions measuring pupils' performance on geometry and measurement. Primary 1 pupils performed better in questions assessing their knowledge of numbers and algebra, with 49.7% scoring between 3 and 5 (60–100%), outperforming 48.2% of primary 2 pupils and 37.3% of primary 3 pupils. In measurement and geometry questions, primary 2 pupils excelled, with 77.1% (the highest percentage across the different strands) scoring between 3 and 5 (60–100%) compared to 52.8% in primary 1 and 42.9% in primary 3. Meanwhile, primary 3 pupils did better than their peers in data handling, with 68.3% achieving scores between 3 and 5 (60–100%) compared to 41.4% in primary 1 and 31.4% in primary 2.

4.5. Factorial ANOVA Composite Results

The results from the end-line data show variations in pupils' performances by gender, school location, and class or grade level and across the different strands. The results also suggest pupils' performance improved across the three strands (numbers and algebra, geometry and measurement, and data). To summarize the findings, we present a factorial analysis of variance to show how the dependent variable (scores) was influenced by the independent variables (gender, school location, and school level). This composite result is depicted in Table 7 below.

Table 7. Multivariate factorial ANOVA.

Source	Dependent Variables	Type III Sum of Squares	df	Mean Square	F	p
Corrected Model	Numbers and Algebra	89.890	11	8.172	4.33	<0.001
	Geometry and Measurement	857.299	11	77.936	24.86	<0.001
	Data	691.245	11	62.840	16.50	<0.001
Intercept	Numbers and Algebra	8518.78	1	8518.78	4510.1	<0.001
	Geometry and Measurement	10,122.23	1	10,122.23	3228.4	<0.001
	Data	7758.08	1	7758.08	2037.4	<0.001
Class	Numbers and Algebra	66.42	2	33.21	17.58	<0.001
	Geometry and Measurement	734.44	2	367.22	117.12	<0.001
	Data	536.22	2	268.10	70.41	<0.001
Gender	Numbers and Algebra	2.209	1	2.209	1.169	0.280
	Geometry and Measurement	1.654	1	1.654	0.527	0.468
	Data	1.559	1	1.559	0.409	0.522
School Location	Numbers and Algebra	16.62	1	16.62	8.80	0.003
	Geometry and Measurement	72.04	1	72.04	22.98	<0.001
	Data	56.27	1	56.27	14.78	<0.001
Class and gender	Numbers and Algebra	0.125	2	0.062	0.033	0.968
	Geometry and Measurement	1.551	2	0.775	0.247	0.781
	Data	3.884	2	1.942	0.510	0.601

Table 7. *Cont.*

Source	Dependent Variables	Type III Sum of Squares	df	Mean Square	F	*p*
Gender, school and location	Numbers and Algebra	0.731	1	0.731	0.387	0.534
	Geometry and Measurement	0.177	1	0.177	0.057	0.812
	Data	0.953	1	0.953	0.250	0.617
Class andschool location	Numbers and Algebra	4.054	2	2.027	1.073	0.342
	Geometry and Measurement	94.992	2	47.49	15.15	<0.001
	Data	93.551	2	46.78	12.28	<0.001
Class, gender, and school Location	Numbers and Algebra	1.064	2	0.532	0.282	0.755
	Geometry and Measurement	1.886	2	0.943	0.301	0.740
	Data	6.519	2	3.259	0.856	0.425

Table 7 shows that, apart from the effects of school location, gender, and class level on pupils' problem-solving competencies, which were already discussed, some interaction effects are worth exploring. The factorial ANOVA results indicate a significant interaction effect between class level and school location for both the geometry and measurement and data strands, with $F\ (2, 518) = 15.15$, $p < 0.001$, and $F\ (2, 518) = 12.28$, $p < 0.001$, respectively. However, the interaction effect of the three independent variables on pupils' number and algebra performance, $F\ (2, 518) = 1.073$, $p = 0.342$, is not statistically significant. Similarly, the analysis revealed that the interaction effect of class, gender, and school location was insignificant in pupils' problem-solving performance across all three strands.

5. Discussion and Implication

Gaining a deeper understanding of how co-creation influences students' problem-solving abilities in mathematics is crucial for enhancing their competencies. This is vital for developing critical thinkers who can thrive in today's globalized world. As noted earlier, the widening learning poverty gap across countries, especially in sub-Saharan Africa, underscores the need for innovative methods in teaching and learning mathematics. Three key points arise from the above results, which are emphasized here. Firstly, the results show that the majority of pupils have varied challenges working with non-routine problems, and this is consistent with the assertion by [14], who argued that despite the efforts and contributions of educators, researchers, and policymakers to guide learners in gaining autonomy in mathematics problem solving, pupils are faced with difficulties that prevent their ability to understand and take responsibility for problem solving. The pupils' challenges were evident in their approaches and scores, averaging 52% in the numbers and algebra, 52% in the measurement and geometry, and 46% in the data strands. The challenges observed varied from pupils' ability to comprehend, abstract, and translate the text into mathematical symbols. Abstraction and symbolization are powerful tools for understanding mathematics and its utilitarian motives in different contexts. To make abstraction and symbolization meaningful to pupils, there is a need for conscious efforts for teachers and educators to use context-specific examples to help bridge the gap between pupils' informal and formal mathematical knowledge. In the current study, all the examples used were designed with cognizance context-specific examples that the pupils were familiar with to help facilitate the abstraction and symbolization process.

Secondly, we considered the relationship between co-creation and the pedagogical approach. As highlighted by [31,33], such partnerships often lead to co-creating materials and strategies that more effectively address students' diverse needs, increasing student engagement and improving academic achievement. The partnership between teachers and researchers led to innovative lesson plans and instructional materials implemented in different classrooms. The effect of the co-creation process influenced the teachers' pedagogical strategies, which in turn impacted pupils' outcomes. A critical analysis of the project's outcomes reveals that co-created lessons and materials significantly enhanced teachers' ability to deliver hands-on, context-specific instruction using appropriate resources. This impact was reflected in the pupils' performance in the end-line study results. The average score in numbers and algebra improved by ten percentage points, rising from 52% to 62%. In measurement and geometry, the score increased by 20 percentage points, from 52% to 72%. Similarly, the data strand saw a 20-percentage-point increase, with scores improving from 46% to 66%. Partnerships between teachers and educators create opportunities to design lessons tailored to the specific needs of both pupils and teachers. These collaborations provide professional development that can be sustained by establishing communities of practice where teachers, educators, and researchers work together to enhance pupils' problem-solving skills and competencies.

Thirdly, it is worth examining the disparity between urban and rural schools and gender. There is clear evidence that rural school pupils risk performing below their counterparts from urban schools as well as the disparity between male and female students in mathematics. It is therefore worth examining the effect of this co-creation process on the performance and learning experiences of pupils from rural schools and females. The study results indicated that female students' performance in the numbers and algebra strand improved by 9.6%, matching the gains of their male counterparts. However, in other areas, female pupils outperformed males, with a 23.6% increase in measurement and geometry compared to 18.6% for males. In the data strand, female students also saw a slightly higher improvement, with a 20.6% increase versus 19.6% for males. Additionally, pupils from rural schools outperformed their urban peers in certain areas. In numbers and algebra, the performance of rural pupils increased by 9.2 percentage points compared to a 7.4% increase for urban pupils. In measurement and geometry, rural students' scores rose by 25.8 percentage points, while urban students saw a 13.8% increase. Notably, 69.2% of rural pupils scored 70% or above in the data strand compared to 63% of urban pupils. These findings suggest that the co-creation process effectively narrowed the disparity gap between urban and rural schools and between male and female pupils in terms of problem-solving competencies.

This study highlights the importance of partnerships, particularly the co-creation of lesson plans and instructional materials by teachers and educators, in enhancing teacher professional practices and improving students' learning outcomes. Expanding such collaborative efforts to other schools, especially in rural areas where students often face diverse challenges in learning mathematics and problem solving, could significantly boost pupils' learning outcomes. It is recommended that teachers remain flexible and actively collaborate with other educators and researchers to develop context-specific lessons and activities that help students bridge the gap between their informal and formal understanding of mathematics.

6. Conclusions

This study examined the effect of co-creating lessons and instructional materials on pupils' problem-solving competencies in mathematics. The utility value of co-creation among teachers and educators is also called for as an alternative way of organizing professional development programs for teachers and the role of research in enhancing the teaching and learning of mathematics.

Most studies have shown the value of collaborations between agents in the education sector to enhance teaching and learning quality. Drawing upon the current findings, there is general agreement that co-creation has become essential in developing lesson plans and activities that support teaching and learning. However, the results from this study have brought to the fore the significant impact of such co-creation activities on the learning experiences and achievements of under-resourced schools and bridging the gender disparity among male and female pupils. The improved performances of these pupils demonstrated the critical role of co-creation in helping reduce the poverty gap in learning that has affected many countries. We conclude that co-creation represents a significant paradigm shift in our efforts to enhance teaching and learning, particularly in mathematics, which remains one of the most challenging subjects in the school curriculum.

Furthermore, it provides compelling evidence that leveraging co-creation alongside the evolving theory of communities of practice is the path forward, as Ref. [16] emphasized. Similarly, Ref. [17] and others have criticized the traditional professional development approach, where educators and researchers dictate new and innovative teaching methods, expecting teachers to apply them without considering the specific context, such as the diverse nature of mathematics classrooms. The co-creation process, however, results in a unified focus on shared priorities. In our study, the teachers and educators collaboratively discussed and developed context-specific activities and materials, leading to professional growth for both groups and improved student learning experiences and outcomes.

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