Improving Students' Problem-Solving Competencies and Mathematical Mindset Through Co-Creation

Final Report

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Executive Summary

This project aimed to enhance students' problem-solving abilities and mathematical mindset through co-creation. Improving problem-solving skills among students has become a significant concern in education. In Ghana, as in many other countries, students' performance in mathematics problem-solving tasks has yet to reach the expected level. For instance, the Trends in International Mathematics and Science Study results from 2007 and 2011 indicate that Ghanaian students performed considerably lower on application and reasoning questions than on knowledge-based ones. Despite efforts in Ghana to help primary school teachers improve their students' problem-solving skills, these strategies still need to be fully implemented. In particular, there is a need for more emphasis on co-creation, where educators actively develop methods to enhance their students' problem-solving competencies.

This study, which was organized into four phases, involved 1,408 students from 15 primary schools. The first phase, the analysis and exploration stage, examined practical problems from various perspectives. This was followed by the design and construction stage, involving six schools, where researchers and teachers collaborated to develop an intervention. This intervention included designing innovative lesson plans and instructional resources to support the teaching of problem-solving. The next phase was the evaluation and reflection stage, followed by the implementation and dissemination stage.

Data were collected using a problem-solving perception survey, a problem-solving assessment tool, lesson observations, and discussions and interviews. Students' performance in all three strands—numbers and algebra, geometry and measurement, and data—showed significant improvement according to the endline data. Notably, the data strand experienced the most substantial gain, with an increase of 1.03 mean points, while the numbers and algebra strand showed an overall performance increase of 0.43. These results suggest that the co-created lessons and activities implemented over eight weeks in the six schools enabled teachers to adopt a more hands-on teaching approach. This improvement highlights that co-creation as an educational method can significantly enhance students' problem-solving abilities and positively influence their attitudes toward mathematics. Teachers strongly supported the continuation of such programs, noting that the collaborative environment fostered by co-creation with researchers and teachers encouraged active participation, creativity, and a deeper comprehension of mathematical concepts. These findings suggest

that educators should integrate co-creation techniques into their teaching practices to cultivate a more supportive and collaborative teaching and learning environment.

Introduction

1.1 Background

The Sustainable Development Goals (SDGs) outline measurable, globally agreed-upon targets to eradicate extreme poverty and hunger, combat lethal diseases, and ensure access to primary education for all children. Specifically, SDG 4 emphasizes creating opportunities to guarantee that all students acquire the knowledge and skills necessary to promote sustainable development. This includes education on sustainable development and lifestyles, human rights, gender equality, fostering a culture of peace and non-violence, global citizenship, and an appreciation of cultural diversity, along with the role of culture in sustainable development (UNESCO, 2017). This objective has been adopted and contextualized within many educational systems, schools, and classrooms. Focus has been placed on UNESCO's (2017) sustainability model competencies, which include systems thinking, anticipatory, normative, strategic, collaboration, critical thinking, self-awareness, and integrated problem-solving skills (see Figure 1).

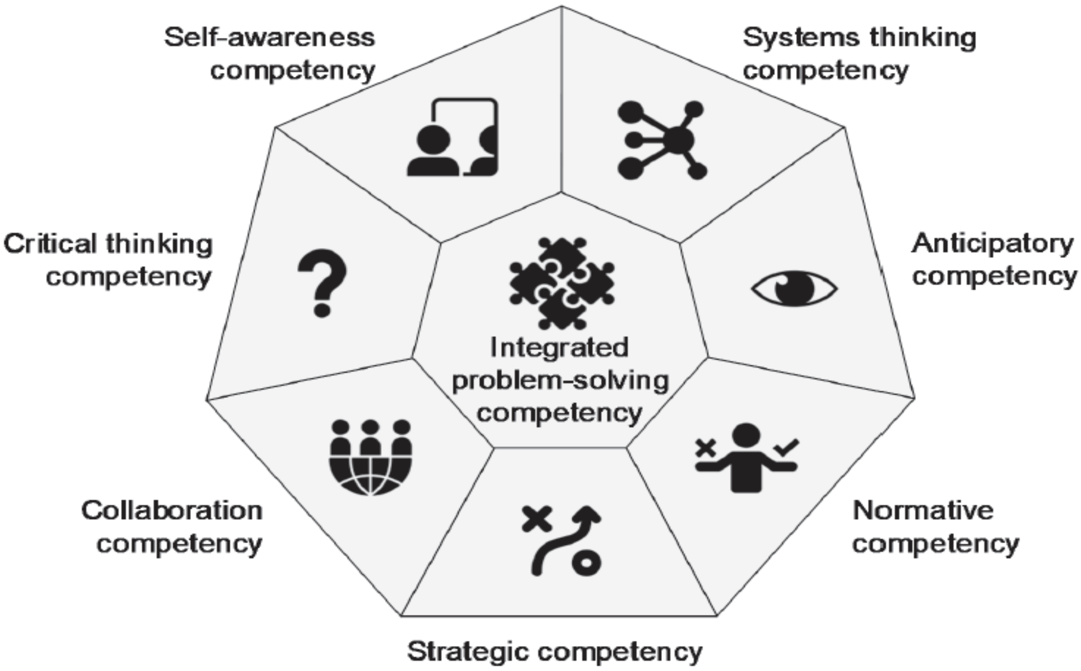


Figure 1. Key competencies for sustainability (UNESCO, 2017)

Improving students' problem-solving competencies has become an issue of major concern in most classrooms, especially in the learning of STEM subjects, and this is enshrined in the UNESCO key competencies for sustainability. The importance of problem-solving is well documented in the literature, and it is therefore not surprising that most school curricula call for the integration of problem-solving in lesson delivery. For example, the Ghanaian curriculum provides a clear framework for promoting students' problem-solving skills and competencies. It states 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" (National Council for Curriculum and Assessment, 2020, p. xiii).

Similarly, there is a plethora of research on the different ways and principles for including problem-solving in the teaching process, especially in mathematics. However, it is worth noting that in Ghana, like in most other countries, students' performance in problem-solving questions in mathematics has not been encouraging, and there is evidence that teacher-designed tests usually contain only a small proportion of problem-solving questions (Ampadu, 2019; Brehmer, Ryve, & Van Steenbrugge, 2016). According to an analysis of recent Programme for International Learner Assessment results, just about 53% of students from participating countries were able to solve problems requiring problem-solving skills (OECD, 2019). Furthermore, students' performance in mathematics in most countries has been plummeting over the years, and students' problem-solving competencies have not been encouraging (Henrekson & Jåvervall, 2016; Nyala et al., 2016; Ampadu, 2019; Narh-Kert, 2020).

In Ghana, several indicators highlight students' underperformance at both primary and secondary education levels in mathematics, which hinders their ability to contribute to national goals and compete in an increasingly technological world. Evidence from national and international assessments over the past decade underscores this issue. For instance, the performance of Ghanaian students in the Trends in International Mathematics and Science Study in 2007 and 2011 revealed that although students generally performed poorly across all three domains—knowledge, application, and reasoning—their performance in application and reasoning questions was significantly lower than in questions assessing their knowledge competencies (Mereku, 2019; Ampadu, 2019). Similarly, the results of the National Education Assessment in mathematics, conducted every two years with a sample of students in grades 3 and 6, show that in the past six years, fewer than 20% of students have achieved the required level of proficiency in mathematics (Mills & Mereku, 2016; Fletcher, 2018).

Despite numerous efforts to address low mathematics performance, recent results show concerning trends. The 2019 Basic Education Certificate Examination revealed low mathematics performance, as noted in the chief examiner's report (WAEC, 2020). Similarly, West Africa's 2021 high school exam results indicated a decline in mathematics scores compared to 2020 (WAEC, 2021). To improve the quality of teaching and learning in Ghanaian schools, the government of Ghana, in collaboration with various stakeholders in the education sector, has implemented several initiatives over the past decades. The Ministry of Education and the National Council for Tertiary Education of Ghana have revised the course content for pre-service teachers to enhance their instructional competence and problem-solving skills (Ministry of Education, 2019). Additionally, the Ghana Tertiary Education Commission, in collaboration with Transforming Teaching, Education and Learning (T-TEL), has developed various modules to support teaching and learning in Ghanaian schools.

However, despite these developments, little attention has been paid to the use of co-creation in improving the teaching and learning of mathematics. Although problem-solving, rooted in cognitivist learning theory, has been promoted by T-TEL to help both pre-service and in-service teachers develop complex mathematical understanding and problem-solving abilities, it has yet to be fully embraced. Many teachers perceive these processes as being imposed upon them rather than collaboratively developed. Effective mathematics teachers acknowledge pedagogy that inspires their students and motivates them to work successfully. Still, teachers wish to be involved in the development of such pedagogies and strategies because it bolsters their ability to help students conceptualize mathematical concepts to effectively apply mathematics in real-life situations as Ghana implements Education 4.0 (Narh-Kert, Osei & Oteng, 2022).

Adapting or adopting different emerging transformative and creative approaches to teaching and learning mathematics (Lotz-Sisitka et al., 2015) has been documented and implemented in many mathematics classrooms. However, most of these interventions are provided by mathematics education researchers and educators and are normally implemented by teachers in different classrooms. Research by Klang et al. (2021) suggests that adapting or adopting these transformative and creative approaches has not yielded the expected results because of the heterogeneous nature of mathematics classrooms, in which students from diverse backgrounds, abilities, and needs are educated together. For this reason, the Conceiving-

Designing-Implementing-Operating 2030 roadmap suggested by Kamp (2021) calls for more structure to consolidate the community of practice, emphasizing stronger involvement in experimentation and the sharing of practice.

It is important to note that designing innovative lessons involves creating challenging activities that stimulate students' thinking and engagement. However, developing these lessons and activities requires instructional resources to provide meaningful learning opportunities (Kaufman, 2019). These resources serve as tools that teachers use to demonstrate concepts, simplify lessons, and make the classroom environment more engaging and easier to understand (Tety, 2016; Tuimur & Chemwei, 2015). A significant barrier preventing primary school teachers in Ghana from integrating instructional resources into their classrooms is the need for these resources (Yeboah et al., 2016; Boakye & Ampiah, 2017; Crankson, Agyeman & Narh-Kert, 2020). This issue persists because schools often need more funds to provide teachers with instructional materials to enhance teaching and learning. To address this, the study focused on designing and using low-cost instructional materials, emphasizing recycled materials, to promote the project's sustainability and ensure that all students, especially those in rural communities where learning poverty is high, have access to learning opportunities.

Furthermore, research indicates that Ghanaian teachers often need more skills in developing and integrating instructional resources into their lessons (Boakye & Ampiah, 2017; Yeboah et al., 2016). This situation highlights the need for co-creation with teachers, enabling them to acquire the necessary skills to recycle and use available low-cost materials to create relevant instructional resources. The co-creation approach used in this study ensured that teachers took ownership of the developed resources rather than simply receiving pre-made materials to use. This collaborative effort in designing materials and lesson plans supported students' learning. It contributed to achieving a minimum proficiency level in functional mathematics, aligning with one of the critical targets of the SDGs.

1.2 Objectives

The study had three main objectives:

1. Conduct school-level (macro), group- or cohort-level (meso), and class- and student-level (micro) needs analyses to understand the problem-solving competencies and mathematical mindset.
2. Develop effective, efficient, context-specific methodologies, lesson plans, low-cost instructional resources, and activities to improve students' problem-solving competencies and mathematical mindset through co-creation.
3. Implement the developed context-specific methodologies, lesson plans, low-cost instructional resources, and activities to form communities of practice to continue sharing ideas for effective, efficient, and context-specific resources.

1.3 Research Questions

The following research questions guided this study:

- What is the status of primary school students' problem-solving competencies?
- How can co-creation help primary school teachers develop effective lesson plans and challenging activities to improve students' problem-solving competencies?
- How do low-cost context-related instructional materials help teach problem-solving and boost the community of practice among teachers?

Methodology

2.1 Research Design

This project utilized the underlying principles of co-creation and design-based research (DBR) by collecting and analyzing quantitative and qualitative data to provide a holistic understanding of the issue under consideration. DBR was considered appropriate for the current study based on the purpose of co-creation between researchers and practitioners (teachers). DBR is an approach that aims to improve educational practice through iterative cycles of product development, design and revision, testing, piloting, data collection, evaluation, redesign, and adoption (Anderson & Shattuck, 2012; Major et al. 2015, p. 3). The structure of the DBR used in this study is depicted in Figure 2.

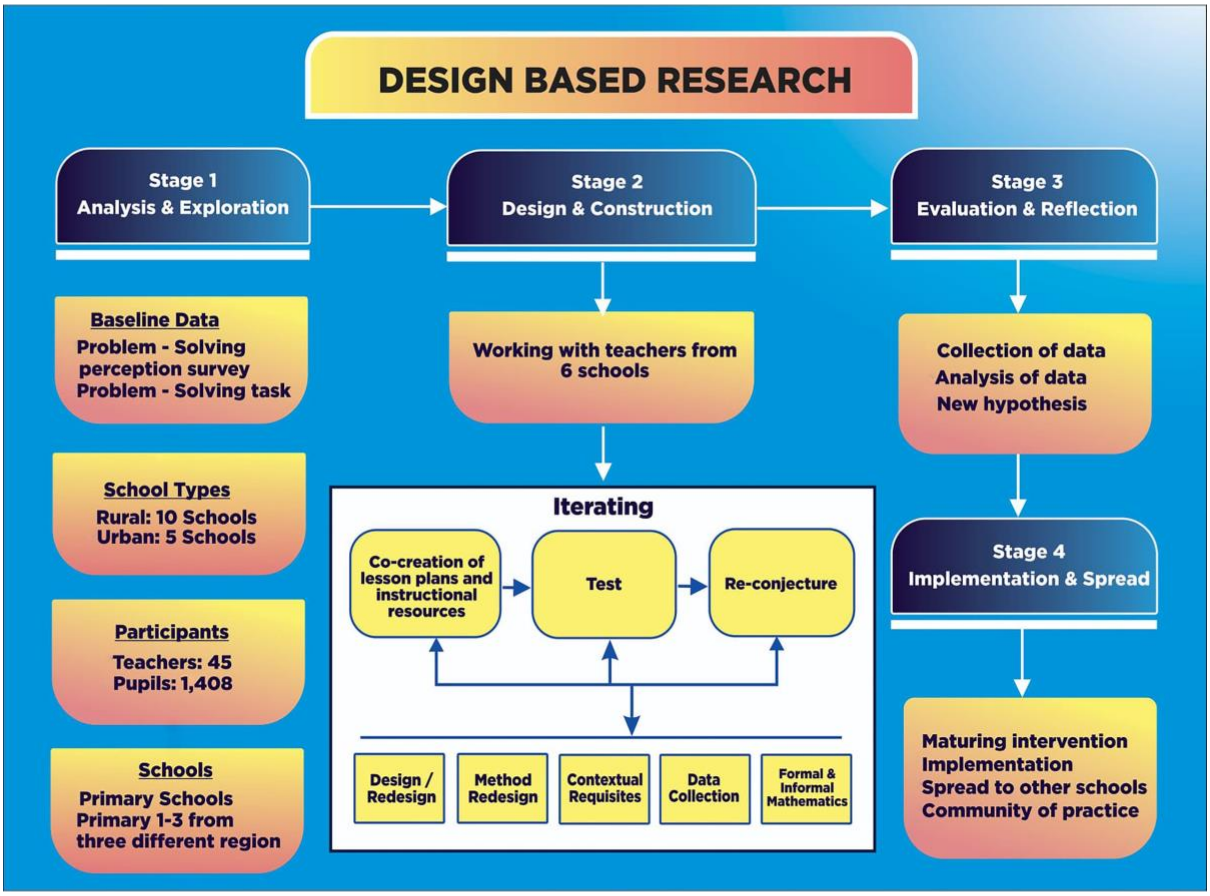


Figure 2. Research design

The study was structured in four phases. The first phase, analysis and exploration, aimed to analyze the practical problem from different contexts. This was followed by the design and construction phase involving six schools, where researchers and practitioners first discussed the results of phase 1 (baseline survey of students' problem-solving competence and perceptions) and then used co-creation to develop an intervention (the design of innovative lesson plans and instructional resources) to support the teaching of problem-solving. Prior research suggested that co-creating these activities would help improve students' problem-solving skills (Doyle et al. 2021) and provide a platform for teachers to collaborate and learn from one another through communities of practice. The design of these lesson plans and teaching resources was piloted, and data were collected to assess their effectiveness and identify potential improvements. Data collected through observations and interviews were analyzed and used to make necessary adjustments to improve the effectiveness of the intervention, taking into account the students' contextual needs and integrating formal and informal mathematics. The third phase involved collecting and analyzing data from the revised intervention. Researchers and teachers reflected on the process, what worked well, what did not, what improvements could be made, and the formulation of new hypotheses.

2.2 Population and Sampling

Two-stage sampling methods were used in this study. A randomized controlled trial was used to select 15 (10 rural and 5 urban) schools from the three regions in Ghana. Forty-five teachers and 1,408 students from 45 classrooms (grades 1–3) were purposively selected to participate in the study's first stage. All schools were informed about the trial and data collection before enrolling voluntarily. The main criteria for selecting the participants were geographical location (by region) and school location (rural and urban) to see the extent to which both students, especially those from rural communities, could benefit from the intervention. Also, gender equality and social inclusion were considered to ensure that all students and schools were given equal opportunities to benefit from the intervention. For the same reasons, six schools involving 18 classrooms and 18 teachers were randomly selected to participate in the study's second phase.

2.3 Instrumentation

Four data collection instruments were used in collecting data to answer the research questions that guided the study. Heppner and Baker's (1997) problem-solving inventory was adopted to test students' problem-solving confidence, self-control, and avoidance style. The instrument had 34 items, had been widely used in different contexts, and had a high-reliability coefficient. However, since the instrument was administered to primary 1–3 students in this study, the researchers identified 15 items (five items each for testing students' problem-solving confidence, self-control, and avoidance style). The choice of these 15 items was based on students' ability to understand the questions. In addition, the instrument was piloted with at least 20 students to ascertain its validity and reliability within the Ghanaian context. The results from the pilot study were used to modify the instrument before collecting the baseline data. The reliability of the modified problem-solving perception survey was evaluated using Cronbach's alpha coefficient. The reliability coefficient was 0.77, considered acceptable, as a Cronbach's alpha of 0.7 or higher is generally deemed reliable (Ursachi, Horodnic, & Zait, 2015).

In addition, a problem-solving assessment tool with five questions was used to collect data about how students approached problem-solving questions and what challenges they faced in solving non-routine questions. The questions were designed with cognizance of the content of the Ghanaian national curriculum. We used standardized questions from the Mathematics Assessment Resource Service relevant to the Ghanaian context. In addition, classroom observations and discussions/interviews between the researchers and the teachers helped collate data to understand the situation and to design and implement effective interventions to support students' learning. The interviews and discussions were between the teachers and the researchers to discuss what needed to be changed or included during the co-creation process. The classroom observation (recording) was done during the co-creation and implementation. It was used to facilitate the discussions between the teachers and the researchers during the co-creation and iteration process. The classroom observation was conducted when the teachers implemented the co-created lesson plans and teaching resources. The purpose of the classroom observation was to provide additional information to facilitate discussions between the teachers and the researchers and improve the co-creation process.

2.4 Data Collection and Analysis Procedures

During the data collection, we anticipated that some participants (primary 1–3) with low reading skills might have needed help to read and understand the questions in the problem-solving survey and the problem-solving assessment sheets. In collaboration with the teachers, the researchers and research assistants read out and explained these questions (in the local language if the need arose) to students so that they could choose the responses (strongly agree, agree, undecided, disagree, or strongly disagree) that applied to them. One of the most essential parts of this research was the iterating and co-creation stage and how the process was done, recorded, and documented. In this study, we audio-recorded all of the interviews and discussions the researchers and the teachers had during the various stages of the iteration and co-creation process. We also took pictures of all practical activities undertaken during this process. The recordings at each stage of the iteration were transcribed and documented for comparison, considering the contextual differences in the school types (rural vs. urban) and grade level (primary 1–3) and teacher characteristics.

To understand the problem-solving perception among the students, we conducted a descriptive statistic to describe participants' perceptions across the three constructs (problem-solving perception, self-control, and avoidance style). In addition, an independent t-test was conducted to determine whether there was any relationship between students' problem-solving perceptions and gender or school location (urban vs. rural). Also, an analysis of variance (ANOVA) was conducted to examine whether there was any relationship between grade level (primary 1, primary 2, and primary 3) and students' problem-solving perceptions. The qualitative analysis was done with cognizance of Braun and Clarke's (2012) six-level thematic analysis (familiarizing yourself with the data, generating initial codes, searching for themes, reviewing, defining and naming, and producing the report).

2.5 Ethical Considerations

Research ethical clearance was obtained from the University of Ghana's ethics committee. Permission was also obtained from the district directors who oversee the schools we selected before they were engaged. Heads and teachers at the schools were also informed about the project so they could decide whether to participate. Consent forms were sent to the heads of schools and teachers who decided to participate. In addition, consent was sought from the parents of students who participated in the survey and the co-creation program.

Results

3.1 Results from the Baseline Study

The baseline study was conducted to examine students' problem-solving perceptions and their problem-solving competencies. Two instruments (see Appendices) were used to elicit this information: a problem-solving perception survey and a problem-solving assessment tool. The problem-solving perception survey had 15 items (five items each testing students' problem-solving competence, self-control, and avoidance style) and used a five-point Likert scale (strongly agree (5), agree (4), undecided (3), disagree (2), and strongly disagree (1)) to measure students' perceptions. Meanwhile, the problem-solving assessment tool was used to measure students' problem-solving competencies and had five items measuring these competencies in numbers and algebra, geometry and measurement, and data. Each strand was scored out of five for uniformity and easy analysis. The results from the data are presented below.

3.1.1 Background characteristics

Table 1 provides a breakdown of participants by gender, grade level, and school location.

Table 1. Demographic characteristics of participants

		Number	Percentage (%)
Gender	Male	688	48.9
	Female	720	51.1
	Total	**1,408**	**100**
Class	Primary 1	434	30.8
	Primary 2	467	33.2
	Primary 2	507	36.0
	Total	**1,408**	**100**
School location	Urban	782	55.5
	Rural	626	44.5
	Total	**1,408**	**100**

As depicted in the table, 1,408 students completed the problem-solving perception survey and assessment tool, of which 688 (48.9%) were male and 720 (51.1%) were female. In addition, there were 434 (30.8%) primary 1 students, 467 (33.2%) primary 2 students, and 507 (36.0%) primary 3 students. Finally, 782 (55.5%) of the students were from urban schools and 626 (44.5%) were from rural schools. The above data show a fair distribution by gender, class, and school location.

3.1.2 Problem-solving perceptions

To understand students' problem-solving perceptions, we conducted a descriptive statistic to describe participants' perceptions across the three constructs (problem-solving perception, self-control, and avoidance style). In addition, we performed an independent t-test to see any relationship between students' problem-solving perceptions and their gender and school location (urban vs. rural). Further, an ANOVA was conducted to reveal any relationship between grade level (primary 1, primary 2, and primary 3) and students' problem-solving perceptions.

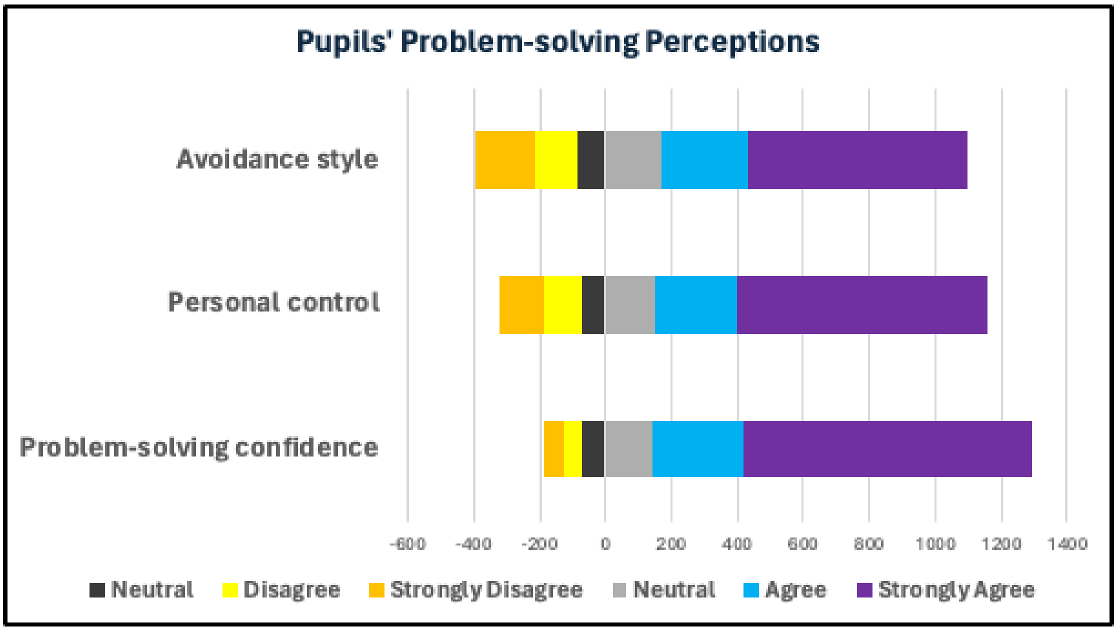


Figure 3. Students' problem-solving perceptions

The descriptive statistics in Figure 3 show that most respondents responded positively to all items in the three constructs. An overwhelming majority—1,151, representing 81.7% of respondents—agreed with the statements measuring their problem-solving confidence. Similarly, 1,011 (71.8%) participants agreed with the statements measuring their self-control. Likewise, 931 (66.1%) respondents indicated their willingness to seek alternative methods when faced with challenging problems. However, it is important to note that the number of respondents who disagreed with the statements from the three constructs increased from 115 (8.2%) for problem-solving confidence to 250 (17.8%) for the questions measuring their self-control and to 310 (22.0%) for the questions measuring their avoidance style. This suggests that around a quarter of respondents were unwilling to seek alternative approaches to solving a problem when faced with difficulties.

Table 2. Independent t-test of gender and problem-solving perceptions

Problem-solving constructs	**Gender**	**N**	**Mean**	**SD**	**df**	**t**	**p**
Problem-solving confidence	Male	688	4.31	0.71			
	Female	720	4.32	0.76	1406	0.33	0.71
Self-control	Male	688	3.96	0.83			
	Female	720	4.00	0.83	1406	0.88	0.34
Avoidance style	Male	688	3.81	0.87			
	Female	720	3.77	0.90	1406	0.84	0.40

*p<0.05

The results in Table 2 show no significant difference between gender and problem-solving perceptions among the 1,408 students who completed the survey, as all p-values for all three constructs are greater than 0.05, accepting the null hypothesis. It is worth noting, however, that female students were more optimistic about the items testing their problem-solving confidence and self-control, with mean scores of 4.32 and 4.0, respectively. Male students, on the other hand, rated the avoidance style more positively (mean 3.81), suggesting that they are more likely than their female counterparts to seek alternative ways of solving challenging problems. The results also show a direct relationship between students' self-control and the other two constructs (problem-solving confidence and avoidance style), which has implications for students' learning and problem-solving skills. That is, supporting students' development of self-control when solving mathematical problems could help improve their problem-solving confidence and avoidance style, which will help improve their problem-solving performance.

Table 3. Independent t-test of school location and problem-solving perceptions

Problem-solving constructs	**School location**	**N**	**Mean**	**SD**	**df**	**t**	**p**
Problem-solving confidence	Urban	782	4.45	0.71			
	Rural	626	4.15	0.76	1406	7.52	<0.001
Self-control	Urban	782	4.10	0.83			
	Rural	626	3.84	0.83	1406	5.75	<0.001
Avoidance style	Urban	782	3.78	0.87			
	Rural	626	3.80	0.90	1406	0.45	0.65

*p<0.05

In addition to the relationship between gender and problem-solving perceptions, an independent t-test analysis was conducted to test whether there was a relationship between school location and students' problem-solving perceptions. The results are presented in Table 3, which shows that the first two constructs (problem-solving confidence and self-control) were statistically significant. The third construct, avoidance style, was not statistically significant; therefore, there was no difference between the problem-solving perceptions of students from urban schools and those from rural schools. The results also show that students from urban schools agreed more with the various statements than their counterparts from rural schools.

The most significant difference was observed in the problem-solving construct, where students from urban schools had a mean of 4.45, compared to 4.15 for their counterparts from rural schools. The avoidance style showed the lowest mean scores: 3.78 and 3.80 for urban and rural students, respectively. However, students from rural schools showed a greater willingness to seek alternative methods of solving challenging problems than their counterparts from urban schools. The results suggest that although students from urban schools responded positively to statements about their problem-solving confidence and self-control, they were not eager to seek alternative methods of solving challenging problems.

Table 4. One-way ANOVA of grade level and problem-solving perceptions

Problem-solving constructs		**Sum of squares**	**df**	**Mean square**	**F**	**p**
Problem-solving	Between groups	9.28	2	4.64		
confidence	Within groups	753.6			8.65	<0.001
			1405	0.54		
Self-control	Between groups	2.61	2	1.305		
	Within groups				1.90	0.150
	Between groups	966.5	1405	0.69		
	Within groups					
Avoidance style		17.57	2	8.79	11.34	<0.001
				0.78		
		1075.9	1405			

The ANOVA results indicate that two of the constructs (problem-solving tendency and avoidance style) are statistically significant: $F(2, 1405) = 8.65$, $p < 0.001$, and $F(2, 1405) = 11.34$, $p < 0.001$, respectively. However, there was no significant difference between grade level and self-control. A critical analysis of the descriptive statistics shows that the majority (about 82.4%) of the primary 3 students responded positively to the problem-solving confidence statements. Approximately 68.9% and 73.2% of primary 1 and 2 students responded positively to these statements. As indicated above, no significant difference existed between students' grade level and self-control perceptions. The descriptive statistics show that approximately 50.8% of primary 3 students, 50% of primary 1 students, and 47.1% of primary 2 students responded positively to the statements measuring their self-control perceptions. For the avoidance style, about 63% of primary 1 students agreed that they would look for alternative methods to solve challenging problems, compared to about 48.8% of primary 2 students and 48.9% of primary 3 students.

Table 5. Independent t-test of gender and students' performance

Strands	**School location**	**N**	**Mean**	**SD**	**df**	**t**	**p**
Numbers and algebra	Male	688	2.40	1.40			
	Female	720	2.46	1.40	1406	1.06	0.29
Geometry	Male	688	2.74	2.10			
and measurement	Female	720	2.81	2.10	1406	0.62	0.53
Data	Male	688	2.22	2.10			
	Female	720	2.43	2.10	1406	1.79	0.73

*p<0

Questions for each category were scored out of five to examine students' performance in the three strands (numbers and algebra, geometry and measurement, and data). The t-test shows no statistically significant difference between gender and students' performance. Female students outperformed their male counterparts in all three strands. The highest scores for both male and female students were in geometry and measurement, while the lowest scores were in questions measuring their competence in data handling.

Table 6. Independent t-test of school location and student performance

Strands	**School location**	**N**	**Mean**	**SD**	**df**	**t**	**p**
Numbers and algebra	Urban	782	2.7	1.30			
	Rural	626	2.02	1.40	1406	9.7	<0.001
Geometry	Urban	782	3.27	1.96			
and measurement	Rural	626	2.16	2.02	1406	10.4	<0.001
Data	Urban	782	2.62	2.67			
	Rural	626	1.97	2.02	1406	5.8	<0.001

*p<0.05

School location is an essential factor that needs to be considered in the teaching and learning process, especially during lesson planning and with regard to the kind of instructional materials that could be used to support learning. Students from urban schools performed better than their rural counterparts in all three constructs, with the most significant difference in geometry and measurement and the slightest difference in data handling.

Table 7. One-way ANOVA of class and performance

Strand		**Sum of squares**	**df**	**Mean square**	**F**	**p**
Numbers and algebra	Between groups	517.5	2	258.76		
	Within groups	2338.93			155.4	<0.001
			1405	1.69		
Geometry	Between groups	1113.44	2	556.72		
and measurement	Within groups				159.2	<0.001
		4911.8	1405	3.49		
Data	Between groups	460.53	2	230.26	57.96	<0.001
	Within groups					
		5581.80	1405	3.97		

*p<0.05

Having examined the relationships between school location, gender, and student performance in the three strands, it was worth looking at how students from the three-year groups performed in numbers and algebra, geometry and measurement, and data. Table 7 shows a significant difference between students' performance and the different strands. The results also show that students in primary 1 performed better than their counterparts in primary 2 and 3 in the questions measuring knowledge of numbers and algebra. Some 83.4% of primary 1 students scored between 3 and 5 (60–100%) on questions in this category. Meanwhile, about 23.1% of students in primary 2 and 32.3% in primary 3 scored between 3 and 5. However, the situation differed in geometry and measurement, where students in primary 2 outperformed their counterparts in primary 1 and 3. Similarly, primary 2 students outperformed their primary 1 and 3 counterparts in questions measuring students' data and data handling knowledge.

3.2 Instructional Materials

One of the aims of this project was to design and produce low-cost or no-cost teaching materials to support the teaching of problem-solving in primary 1–3 mathematics. The researchers and educators met with the teachers in the six schools to discuss developing the materials. Despite the common understanding between the teachers, researchers, and educators about the importance of co-creating these materials, finding an appropriate and sufficient time for the co-creation of the materials was a challenge because the teachers had started their normal school term and were unable to spend approximately three to five hours a day for three weeks on the co-creation of the materials. It was therefore decided that the materials expert would design the materials based on the content of the national curriculum, and the teachers would discuss their use and implementation with these experts. This means that the materials developed needed to relate to all strands of the curriculum (numbers and algebra, geometry and measurement, and data). The materials were designed for all 15 schools and the 45 teachers participating in the study's first phase.

Figure 4. Presentation of instructional materials

The six schools for the co-creation process were divided into three zones (Dodowa, Adenta, and Swedru), with two schools in each zone. Each zone had six teachers, and the presentation and discussion of the teaching materials were done with the focus of the project and co-creation in mind. Teachers and researchers exchanged ideas about the different concepts that could be taught with each material, the perceived challenges, and how these challenges could be minimized. As shown in Figure 4, some of these materials included an improvised abacus, a chart for teaching data handling, a grid for teaching multiplication, different 2D shapes and 3D objects, and others. During the presentation, the teachers and researchers had the opportunity to discuss the various ways that these materials could be used to support learning, and some of the teachers took turns demonstrating how they would use the materials to teach different concepts. It is worth noting that the teachers were allowed to come up with other ideas for using materials that were outside the scope of what the researchers and educators had assumed.

3.3 Co-Creation

Researchers and teachers worked together in this phase to develop sample lesson plans, focusing on designing activities to support students' learning and solving non-routine problems. The overall aim was to be able to design lesson plans with challenging but context-specific activities that would help bridge the gap between students' informal and formal mathematical knowledge. The co-creation took place in three phases. In phase 1, teachers were asked to collaborate and design a sample lesson they would like to teach. This was to encourage teachers to work together given that they were coming from different schools and had not necessarily had the opportunity to work together before. The teachers worked together to prepare sample lesson plans, and then the researchers, educators, and teachers discussed the lesson plans to better understand the chosen topic, the activities, and how the lesson could be delivered in the different classrooms. Examples of the prepared lesson plans are shown in Figure 5.

Sample Lesson Plans

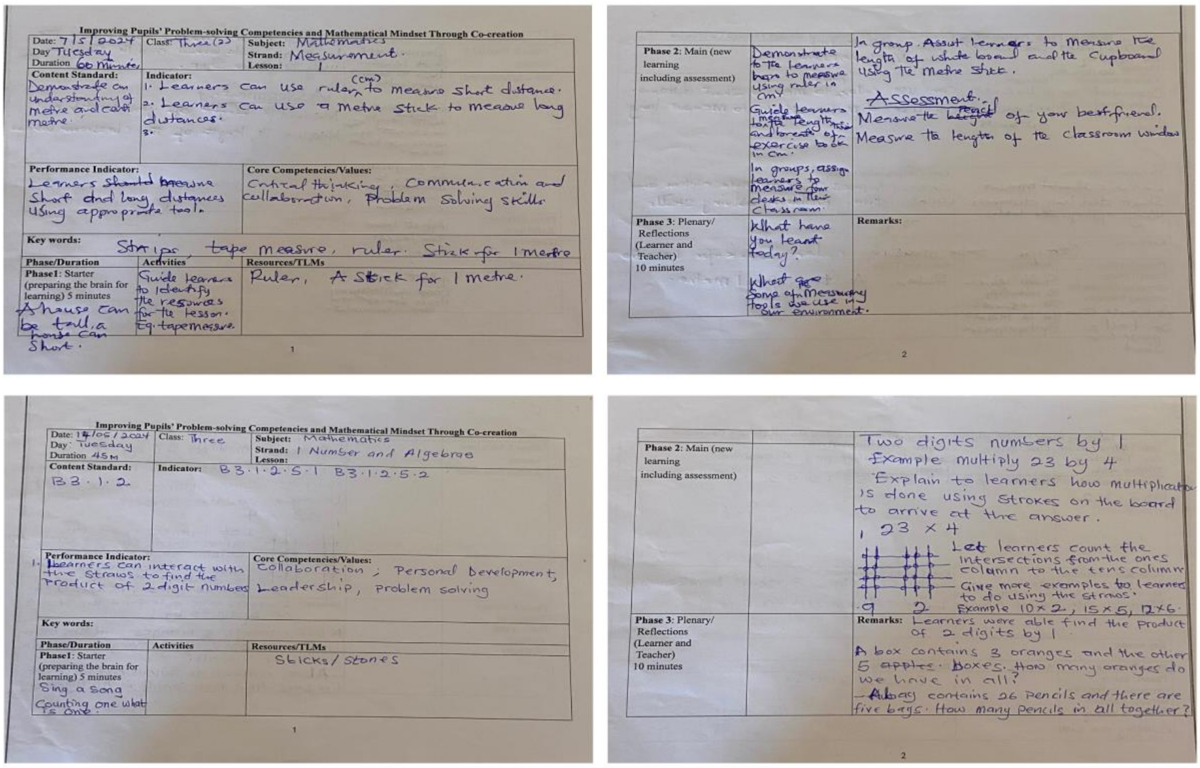
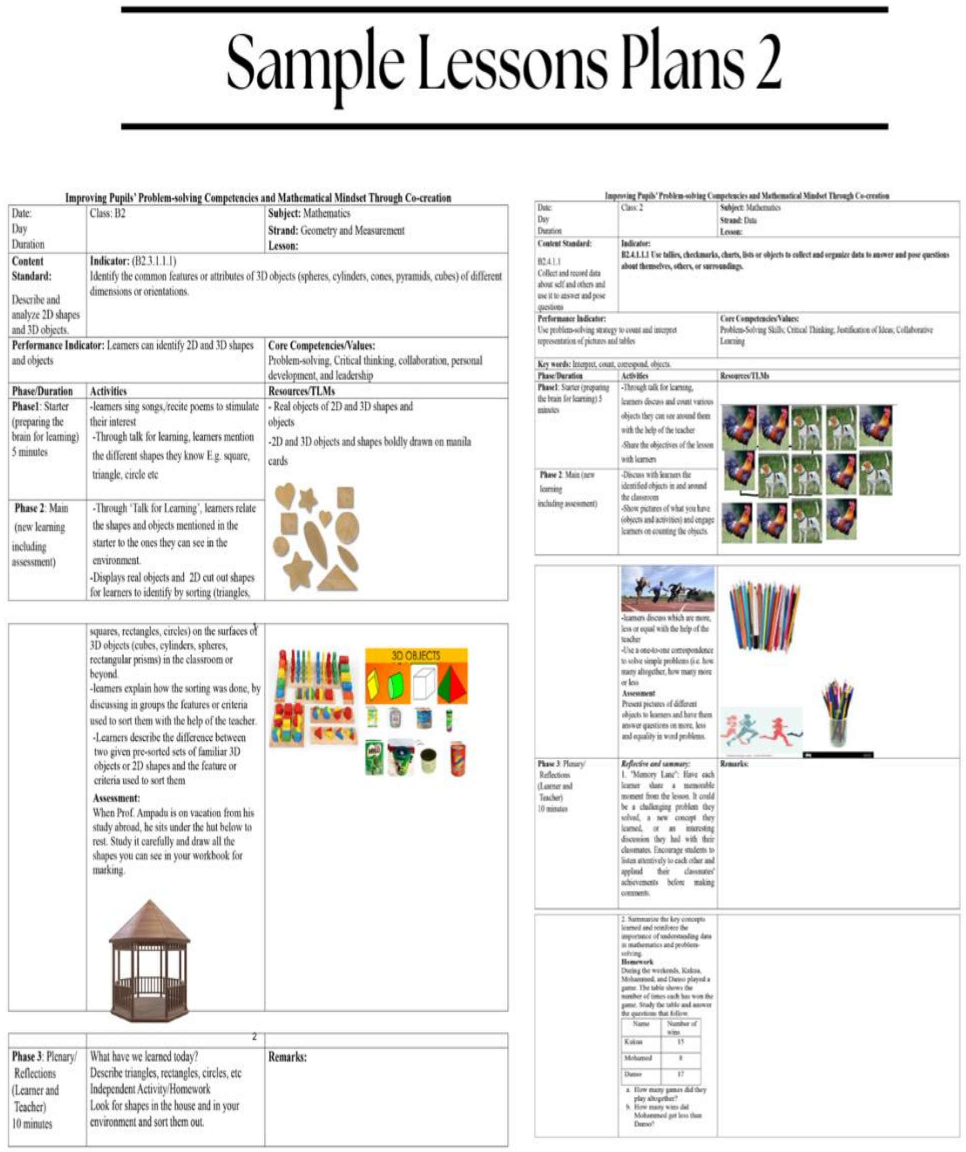


Figure 5. Sample lesson plans from teachers

In phase 2, researchers and educators brainstormed on the different components of the lesson plans and agreed on specific lessons to co-create based on the topic and strands that the teachers would be teaching in the coming week. Based on this, different lesson plans were co-designed for the different classes in each zone. Figure 6 shows examples of the co-designed lesson plans. During the discussion, it was noted that as the teachers in each zone were from urban or rural schools, it was easier to adapt the lesson to their respective contexts. This helped make the process more engaging and address context-specific needs or challenges.



Sample Lessons Plans 2

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 Prof. Ampadu is on vacation from his study abroad, he sits under the hut below to rest. Study it carefully and draw all the shapes you can see in your workbook for marking.	3D OBJECTS
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:**

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

Date: Day Duration	Class: 2	**Subject:** Mathematics **Strand:** Data **Lesson:**
Content Standard: B2.4.1.1 Collect and record data about self and others and use it to answer and pose questions	**Indicator:** **B2.4.1.1.1 Use tallies, checkmarks, charts, lists or objects to collect and organize data to answer and pose questions about themselves, others, or surroundings.**	
Performance Indicator: Use problem-solving strategy to count and interpret representation of pictures and tables		**Core Competencies/Values:** Problem-Solving Skills; Critical Thinking; Justification of Ideas; Collaborative Learning
Key words: Interpret, count, correspond, objects.		
Phase/Duration	**Activities**	**Resources/TLMs**
Phase1: Starter (preparing the brain for learning) 5 minutes	-Through talk for learning, learners discuss and count various objects they can see around them with the help of the teacher -Share the objectives of the lesson with learners	
Phase 2: Main (new learning including assessment)	-Discuss with learners the identified objects in and around the classroom -Show pictures of what you have (objects and activities) and engage learners on counting the objects. -learners discuss which are more, less or equal with the help of the teacher -Use a one-to-one correspondence to solve simple problems (i.e. how many altogether, how many more or less **Assessment** Present pictures of different objects to learners and have them answer questions on more, less and equality in word problems.	
Phase 3: Plenary/ Reflections (Learner and Teacher) 10 minutes	***Reflective and summary:*** 1. "Memory Lane": Have each learner share a memorable moment from the lesson. It could be a challenging problem they solved, a new concept they learned, or an interesting discussion they had with their classmates. Encourage students to listen attentively to each other and applaud their classmates' achievements before making comments. 2. Summarize the key concepts learned and reinforce the importance of understanding data in mathematics and problem-solving. **Homework** During the weekends, Kukua, Mohammed, and Danso played a game. The table shows the number of times each has won the game. Study the table and answer the questions that follow.	**Remarks:**

Name	Number of wins
Kukua	15
Mohamed	8
Danso	17

a. How many games did they play altogether?
b. How many wins did Mohammed get less than Danso?

Figure 6. Sample co-created lesson plans

In phase 3 of the co-creation process, the teachers, educators, and researchers critically examined each section of the co-created lesson plans. They discussed how these could be delivered in different classroom contexts. During the discussion, one of the major concerns was the availability of instructional materials for the lessons, and the teachers were assured that each class would be given a pack of instructional materials to facilitate the delivery of the lessons. Figure 7 includes some pictures taken during the discussions.

Figure 7. Co-creation of lesson plans

3.4 Lesson Observation

The next phase of the co-creation process was implementation, where teachers implemented the lesson plans in their respective classrooms. A total of 18 lessons were observed, and the purpose of the observation was to facilitate discussions during the reflection and iteration processes. For consistency, an observation schedule was used during each observation. The observation schedule had four sections: lesson design, student participation, teacher-student relationship, and use of materials. Figure 8 shows examples of completed observation protocols for the different classes.

Sample Lessons Observation

BACKGROUND INFORMATION

Name of School: Agona Swedru A.M.A "B" Basic School.........Topic: Addition and subtraction...... Date: 15-05-2024

Class: 3.................. Number of Students: 32...

Lesson Starts: 9:18 am............ Lesson Ends: 10:10 am......

LESSON DESIGN		**Description of Events (describe what was observed)**
Students Prior knowledge was reviewed	Yes **No**	Pupils prior knowledge was not reviewed. The lesson started with a counting song. After that the teacher using some of the instructional materials introduced the topic for the lesson.
The teaching strategy (gies) used	Lecture Method **Activity Method** **Demonstration Method** Group Work **Discovery Method**	The teacher employed both demonstration and activity method during the lesson The class was full of activities from the pupils. The teacher did a lot of demonstrations using the instructional materials to enhance the pupils understanding of the topic. Some activities such as counting using bottle tops were performed by the pupils to further enhance their knowledge in the topic. New method or technique of addition was shown by the teacher to the pupils which challenged the pupils to think
The lesson was designed to develop students understanding of a particular concept.	**Yes** To some extent No	The lesson was focused on helping the pupils understand the concept of addition and subtraction. Different methods such as discovery, demonstration and activity were used to enhanced their understanding. Practical problems were given to the pupils to solve with the outcome being positive.
The lesson focus and direction were determined by ideas from students	Yes To some extent **Never occurred**	From my observation, the focus and direction of the lesson was determined by the teacher with the goal of helping the understand the concept and introducing them to new lexicons such as put together, combine in place of addition
The lesson engaged pupils	**Yes** To some extent Never occurred	The pupils were engaged throughout the lesson which in my opinion was partly because of the instructional materials which they were using for some counting.
The teacher used the prescribed textbook for the lesson.	Yes Sometimes Never occurred.	A government supplied mathematical textbook together with the instructional hangout provided through the co-creation was used by the teacher for lesson
STUNDENTS PARTICIPATION		**Description of Events (describe what was observed)**
Pupils played active role in the teaching-learning process	**Yes** Sometimes Never occurred	The lesson was full of activities from the pupils with some videos and pictures taking during the lesson showing as evidence
Pupils were allowed to discuss their ideas with their colleagues.	Yes Sometimes **Never occurred**	From my observation, discussion during the lesson was between the pupils and the teacher.
Pupils were given the chance to find ways of solving problems on their own.	**Yes** Sometimes Never occurred	From my observation, pupils were given several example question with the teacher helping them to solve, after that similar questions but in different forms were giving to the pupils to solve which some were able to solve
Pupils were encouraged to use variety of methods in solving problems.	**Yes** Sometimes Never occurred	New method of addition was demonstrated by the teacher to the pupils which was different from the normal way of addition. I was personally very glad to observe that.
Pupils were encouraged to make predictions and discuss their mistakes	Yes Sometimes Never occurred	During the initial and the middle parts of the lesson, mistakes of the pupils were discussed and corrected but getting to the end of the lesson, some mistakes were overlooked. This was due to the fact the lesson was still ongoing during their break time so there was a bit of rush there but this did not have any negative impact on the lesson
Pupils were given the chance to ask questions.	**Yes** Sometimes Never occurred	Pupils had the chance to ask questions but only few.
Pupils' questions were given the needed attention	**Yes** Sometimes Never occurred	Those who were able to ask questions received the needed attention from my observation
Pupils were given the chance to perform investigations in developing their own understanding.	Yes Sometimes **Never occurred**	Such never occurred during the lesson
There was a high proportion of students talk.	**Yes** Sometimes Never occurred	Yes, majority of the pupils talked during the lesson. In fact, a lot of questions were asked so almost all the pupils had the chance to talk and make mistakes during the lesson.
TEACHER/STUDENT RELATIONSHIP		**Description of Events (describe what was observed)**
Pupils' participation was encouraged and valued	**Yes** Sometimes Never occurred	Yes, I was personally happy with their participation and attention during the lesson and answers given by them were valued by the teacher whether correct or wrong
The teacher acted as a facilitator in the teaching learning process	**Yes** Sometimes Never occurred	The lesson was full of activities to the pupils. The teacher in fact asked them a lot of questions during the class. If this is how the teacher teaches the class every day and not because and external person was observing, then I will say she is a real facilitator
The teacher took his/her time to explain things to pupils	**Yes** Sometimes Never occurred	She was very patient during her delivery and also understood her pupils very well

There was equal respect among the teacher and the pupils.	**Yes** Sometimes Never occurred	Yes, no one was look down upon. Every pupil was treated with respect whether providing wrong answers or not
USE OF INSTRUCTIONAL RESOURCES		Description of Events (describe what was observed)
What instructional materials were used?	Abacus, bottle top	The bottle top and the abacus provided them were extensively used during the lesson
At what stage of the lesson was the instructional materials used?		The instructional materials were used right from the onset of the lesson to the end. Every example was demonstrated using the instructional materials
How were the instructional materials used?		The abacus was used by the teacher for demonstration and the bottle tops were extensively used by the pupils for counting purposes
Pupils were allowed to freely engaged with the instructional materials	**Yes** Sometimes Never occurred	Yes, the pupils had a feel of the materials, and this also enhanced their participation during the lesson

Figure 8. Samples of observation notes

Our analysis of the observation data shows that most of the teachers tested their students' prior knowledge using a variety of approaches, such as questioning and discussion. Teachers also used different teaching methods in the classroom, with activities, demonstrations, and group work being the most frequently used strategies. Given this variation, we plan to compare these strategies across classes and school sites. Student engagement is a critical component of the teaching and learning process, and it is worth noting that the preliminary results show that in all 18 lessons observed, teachers made a conscious effort to engage students in the process. However, the results also suggest that despite student engagement, the focus and direction of most of the lessons observed were determined by something other than student ideas. This could be a great asset in the teaching-learning process, where the teacher and the students work together to improve the lesson and enhance students' learning experience. The use of instructional materials was paramount in all of the observed lessons. Teachers used both the instructional materials given to them as part of the project and the materials that they already had. The results show that almost all teachers used the instructional materials throughout the lessons. Figure 9 depicts pictures taken during the classroom observations, showing how the teachers and their students used the different instructional materials.

Figure 9. Lesson observation pictures

3.5 Reflection

After piloting the lesson plans and materials, it was important to reflect with the teachers to discuss their effectiveness and identify potential improvements. One of the aims of this process was to facilitate the iterative process of designing and redesigning the lesson plans and methods, considering the contextual needs of the students. To achieve this, the researchers and teachers discussed the implementation process and suggested changes and improvements. Figure 10 shows some pictures taken during the reflection process.

Figure 10. Reflection after co-creation and lesson delivery

The reflection process was guided by the following themes: lesson approach, use of instructional materials, what worked well, use of different approaches, challenges incorporating the instructional materials, changes to lesson plans, challenges solving non-routine problems, and improving students' problem-solving skills. Here, we present individual cases (grade level) and cross-case analyses of the results from the reflection process.

3.5.1 Lesson approach

To understand the reasoning behind how teachers began their lessons, we asked them to describe their lesson introductions and explain their chosen methods. The analysis of our conversations with primary 1 teachers revealed that all of them used counting and rhyme songs to start their lessons on addition. The teachers believed that this strategy effectively engaged students and prepared their minds for learning. They highlighted the importance of using catchy lyrics and actions to help students become familiar with numbers before moving on to specific mathematical operations. By using songs that illustrate increasing or decreasing number patterns, teachers aimed to help students grasp the concepts of addition and subtraction. This approach was beneficial in building a foundational understanding and easing the transition into more formal instruction. One teacher described this method as follows:

> *We did addition. And so, we started with a song. One and one-two with action two and two four …, three and three are six for me … four and four eight, five and five ten little fingers of my hand. Ahaa! So, we started that. So, I asked them why we did one and two. Then they said that one plus one is equal to two. Then I introduced the lesson that we were coming to do addition, so we learned the new word numbers. We started it that way because we were going to learn about addition; I wanted them to capture the numbers before maybe we start adding the numbers we've mentioned all together, that's why.*

Primary 2 teachers also mentioned starting their lessons with a rhythm and a warm-up exercise, a common strategy to engage students and capture their attention. This approach aligns with the new curriculum guidelines. This is evident in the response from one of the teachers:

> *We use songs as a starting point to engage the students and generate interest in the upcoming lesson. The songs were reflective and connecting tools, aligning with the RCA (Reflect, Connect, Apply) framework. This approach aimed to stimulate curiosity and prepare the students for the lesson content.*

Primary 3 teachers also noted that when beginning a lesson, it is important to spark students' interest by engaging them in brief mental exercises. These activities include songs, fraction riddles, counting figures, and counting objects in the classroom. All the teachers expressed enthusiasm for using songs related to the lesson content to engage their classes. However, some teachers did not use songs during their lessons, explaining that this was because the fraction songs available on YouTube were difficult for them to learn and use.

3.5.2 Use of instructional resources

To understand how teachers utilized instructional materials, we asked them to reflect on their use of these resources. A primary 1 teacher explained that they used teaching and learning materials (TLMs) such as the abacus, stones, and straws and engaged students in hands-on activities. Students were organized into groups and given tasks that promoted active participation and collaboration. Furthermore, teachers encouraged student-led learning by allowing students to independently use the materials to complete exercises, which led to a successful understanding of mathematical concepts. For counting exercises, some teachers distributed stones among their students and used the abacus and straws to represent numbers and operations visually. Teachers integrated these TLMs with those provided by the school, creating a conducive learning environment. Two teachers described their experiences as follows:

> *I grouped them after I introduced the abacus. I called one or two of them to come and do the same thing and then grouped them. I shared mine with them. So, I gave the exercise on the board and said, Group One, you are answering number one; Group Two, you are answering number 2, and before I finished, they had already finished, yeah. I made them handle it, but today, the pupils used it to do the exercise because we were time-bound yesterday so that they couldn't use it. And they were able to get the answer correct. It's only two or three … I have some special children in the class, so they were the only pupils who could not. Out of 24, 21 were able to do. But I made them handle the material, those special children. I made them to handle it.*
>
> *After introducing them to how to use the resource, I called a pupil. After I finished doing it, they said I called a pupil to come and do it. That's a boy. After he had finished, I called a girl. After that, I put them in a group. So maybe like four groups, and I chose a leader for them. I put the resources in front of them. I gave them a tax, one tax each. Then they all use the abacus to add it.*

Primary 2 teachers utilized TLMs to demonstrate fractions, and the process involved showing a whole object, dividing it into halves and quarters, and allowing students to replicate the process with paper. This hands-on approach was consistent across the teachers, and some of these teachers indicated that such visual and tactile methods significantly aided pupils' understanding. Visual aids like drawings helped students grasp complex mathematical concepts like fractions, and one of the teachers emphasized the importance of hands-on activities in promoting comprehension and retention among students.

All primary 3 teachers recognized that students were enthusiastic about using the TLMs. They appreciated these innovative resources, noting that they significantly enhanced their lessons. TLMs increased students' engagement, improved their understanding of concepts, and bolstered their problem-solving skills. Teachers in Adenta shared that using such materials was routine for them, as they frequently mentor student teachers and integrate TLMs into their lessons. One teacher mentioned that they update their TLMs every term, typically every two to three months. Despite their familiarity with TLMs, teachers expressed a desire for training on how to create these resources themselves. This suggests that the TLMs they receive are often made from low-cost or readily available materials, highlighting a potential area for further development.

3.5.3 What worked well?

When asked about what went well, most teachers reported that the availability of instructional resources played a significant role in the effectiveness of their lessons. Primary 1 teachers highlighted that using resources, notably the abacus, significantly engaged students and improved their understanding of addition concepts. They observed that the abacus positively influenced student involvement and contributed to a smooth lesson delivery by promoting active participation. Teachers noted consistent success with the abacus, as it helped students arrive at correct answers. They shared the following observations about the abacus's positive impact on student engagement and comprehension of addition concepts:

> *I could see that it worked very well because they found interest in using it to add the numbers. Like the abacus, this thing everybody wanted to try his or her hands on it. So, it helped a lot. So that made them to grasp the concepts easily.*
>
> *With what went well, I think it helped them. All those I called never got their answers wrong when using the abacus. They got it right. It's just that it was not enough.*

> *Just as my colleague said. After the introduction, as soon as I started the lesson and brought out the TLMs, they were happy and involved. We were all involved, and then the lesson went smoothly.*

Primary 2 teachers reported that using TLMs significantly boosted student engagement and involvement in their lessons. They observed that hands-on activities, like folding paper to explore fractions, kept students interested and supported their understanding. Despite some initial anxiety due to the presence of research assistants, the overall interaction between teachers and students was positive. The new instructional strategies were well-received, leading to active participation and improved lesson comprehension. All primary 3 teachers agreed that their lessons and objectives were successful thanks to TLMs. They attributed this success to the students' active participation and enthusiasm. One teacher noted that incorporating data such as students' favorite foods, colors, and sketches of dogs on the board made the lesson exciting and engaging. Other teachers mentioned that using the actual abacus in class—as opposed to only seeing it in a textbook—improved participation and engagement.

3.5.4 Challenges in incorporating the materials

Primary 1 teachers reported several issues, including limited access to and usability constraints with instructional materials. They experienced delays in using materials due to technical problems, such as small holes in bottle cutouts and inefficiencies in resource distribution, particularly the abacus. Time constraints also affected students' ability to become familiar with the abacus tool before the lesson. Despite these challenges, students used the tool the next day, with only 3 out of 24 students needing help in using it effectively due to their special needs. Some teachers found the abacus less conducive to interactive learning than other resources, such as straws, which allow for greater student involvement. Primary 2 teachers faced challenges related to limited resource access and larger class sizes. Teachers from Adenta noted that the insufficient availability of TLMs led to noise and disruptions as students competed for the limited resources. Grouping student for activities was also occasionally difficult, particularly in managing class dynamics and ensuring that all students actively participated.

3.5.5 Use of different approaches

We probed further to determine whether the teachers would incorporate different teaching methods following the co-creation process. Primary 1 teachers indicated that they had reflected on their teaching methods and identified areas for improvement for future lessons. They were committed to adjusting, such as starting with tangible objects before introducing abstract numbers to enhance comprehension. They also planned to use real objects for practical learning experiences and incorporate written instructions on the board to support understanding. Teachers recognized the importance of distributing resources like abacus sticks among student groups to improve engagement. Additionally, some teachers suggested incorporating a wider variety of TLMs into future lessons to facilitate full participation and engagement. One teacher shared the following insights:

> *I realize that I talked a lot. I should have written the thing on the board like the sentence, like in the statements. I said it orally, forgetting I should have written it on the board for them to read before coming out with the mathematical numbers like Kofi had 15 something … I should have written the sentence ahaa!*
>
> *Concerning the use of the abacus—for me, I didn't share the sticks to the groups sticks to the groups. We used it one at a time. So maybe next time I will go by that by sharing the sticks with the groups.*

Primary 2 teachers expressed the desire to use real objects, such as oranges or watermelons, to teach fractions in future lessons. These tangible items could offer a clearer representation of dividing wholes into parts, thereby aiding students' understanding of the concept. They also emphasized the importance of ensuring accuracy in drawings and demonstrations, as inaccuracies could lead to confusion. When faced with inadequate TLMs, teachers suggested alternative methods, such as using student volunteers or creating visual aids like drawings. They highlighted the crucial role of resource availability in facilitating effective teaching and learning experiences and underscored the need for ongoing support and investment in educational materials.

3.5.6 Changes to the lesson plans

Teachers suggested several adjustments to the lesson plans to enhance teaching effectiveness. They emphasized the need to supplement existing lesson materials with additional stories to enrich the learning experience. Some teachers proposed modifications to resources such as the abacus, including widening the holes in the cutouts and incorporating more interactive elements to ensure better shareability among students. These adjustments are believed to improve engagement and create more effective student learning experiences. Below are some of their narrations:

> *We need to add more stories because the stories are not enough.*
>
> *I said earlier that the holes were smaller. So, I would suggest that, or I have planned to cut some and make the holes a little bigger. That is what I want to do.*
>
> *I think maybe the resources, like how you did the abacus. It was in such a way that it is shareable. So, I will suggest that maybe you see the shapes too … Maybe … when you are doing more resources, you can. You can do it in the form of it being maybe shareable. So that each student maybe can have a feel.*

3.5.7 Challenges faced by students in solving non-routine questions

All the teachers agreed that a significant challenge faced by students when solving non-routine questions stems from their inability to read and understand the questions. Teachers from Adenta and Asebi noted that lower primary teachers are encouraged to focus on teaching reading skills, even if students do not fully understand the words initially, with the expectation that comprehension will develop in upper primary. One teacher also mentioned that problem-solving questions are not heavily emphasized in their curriculum, except in contexts like dealing with money. Another teacher indicated that in a class of 64, only about 10 students have the required English textbooks, affecting their ability to engage with the material effectively. One teacher explained that she often clarifies phrases and words by reviewing keywords with students, which helps them grasp the concepts being taught. She added that sometimes students help one another by translating sentences into the local language. Another teacher mentioned holding one-on-one discussions with students, particularly those with lower abilities, to ensure that they understand the concepts.

3.5.8 Ways to improve students' problem-solving skills

- It is necessary to consciously use more TLMs in the lessons, as they facilitate easy teaching and learning.

- Collaboration is needed to enhance lesson delivery and problem-solving techniques.
- Class teachers should meet regularly to engage in discussions and develop additional TLMs.
- There is a need for more workshops for professional development and knowledge of new teaching methods.
- More interesting mathematics textbooks should be designed in order to arouse students’ interest.
- The cumbersome and bulky nature of the curriculum should be addressed in order to foster easy teacher understanding and proper assimilation of concepts by students.
- Equal lesson plans for mathematics should be designed for all teachers.
- Sufficient resources like textbooks should be provided on time to facilitate easy teaching.
- There is a need for lower- and no-cost TLMs to facilitate an easy understanding of the concepts being taught.
- Teachers should adopt more problem-solving questions instead of just asking simple figure questions with mathematical symbols of addition, subtraction, or multiplication.

3.6 Results from the Endline Study

This research followed a three-stage approach. Initially, baseline data were collected to establish the perceived state of the problem. Following this, an intervention was conducted to determine how the co-created materials could support the teaching and learning process, with a particular focus on co-creation and enhancing students’ problem-solving skills. After the intervention, endline data were collected to evaluate the impact of the intervention. This section of the report combines the baseline and endline data results. For consistency, only the results from students who participated in both the baseline study and the endline study were included. Table 8 presents the demographic profile of the students from the six schools involved.

Table 8. 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**

As shown in the table, 283 students (53.4%) who completed the problem-solving tasks were male, while 247 students (46.6%) were female. Regarding school location, 280 students (52.8%) were from urban schools, and 250 students (47.2%) were from rural schools. These statistics are comparable to the baseline data, where approximately 48.9% of participants were female and 51.1% were male. Additionally, the baseline data indicated that 55.5% of participants were from urban schools, while 44.5% were from rural schools.

3.6.1 Student performance by strand

To understand the effect of the co-creation process, we compared students' performances in the baseline and endline assessments. For consistency, we used data only for those students who participated in both assessments. This approach allowed for a more accurate evaluation of any changes in performance resulting from the co-creation process. Table 9 presents the results.

Table 9. Student performance by strand

	Baseline data results			Endline data results					
Strand	**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

$p<0.05$

Table 9 illustrates a significant improvement in students' performance in the endline assessment across all three strands. Specifically, students' overall performance in the numbers 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. Students demonstrated substantial improvement in their mathematics performance, which could be attributed to the fact that co-created lessons and activities enabled teachers to adopt a hands-on teaching approach that engaged students to use context-specific instructional materials.

3.6.2 Student performance by gender

In addition to the general results, a cross-case analysis was conducted to determine if there were significant differences in students' performance based on independent variables. The first analysis explored the relationship between gender and performance, with the results displayed in Table 10.

Table 10. Independent t-test of gender and student performance

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

$p<0.05$

As shown in the table, there is no significant difference between students' performance and their gender, similar to the findings from the baseline data, which also showed no significant difference between gender and performance. However, it is worth noting that a critical analysis of the descriptive statistics shows that both male and female students' performance improved across all three strands. Female students' performance increase was more significant in geometry and measurement and data than their male counterparts. The mean improvement in male students' performance in numbers and algebra at the endline was 0.48, surpassing the 0.38 increase observed in their female counterparts. However, female students outperformed males in geometry and measurement and data competencies, with mean increases of 1.12 and 1.04 points, respectively.

3.6.3 Student performance by school location

For this study, two locations (urban and rural) were used to classify the schools. There is a general perception that students from urban schools usually perform better than their counterparts from rural communities due to several factors, including the availability of instructional resources and better instructional quality. In this section, we discuss how students' performance differed across urban and rural schools and whether the co-created lessons, activities, and resources led to any increment in students' performance. Table 11 presents these results.

Table 11. Independent t-test of school location and student performance

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

$p<0.05$

The results show a significant difference in students' performance according to school location. Urban students outperformed their rural counterparts in numbers and algebra and in geometry and measurement. Further analysis also indicates that the performance of students from urban and rural schools improved across all three strands. However, it is worth noting that students 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 students in questions measuring their competencies in numbers and algebra, as well as geometry and measurement, respectively, which is above that of their urban counterparts. The results confirm the initial assertion that students from urban schools usually perform better than their counterparts from rural schools. However, the observable improvement in the performance of rural school students across the three strands cannot be underestimated. We can argue that the co-created lessons and instructional materials have positively impacted students' performance, especially those from rural schools.

3.6.4 Student performance by grade level

This section discusses the relationship between students' problem-solving performance and their grade level. We used ANOVA to explore these differences. Table 12 depicts the results.

Table 12. One-way ANOVA of grade level and performance

Strand		**Sum of squares**	**df**	**Mean square**	**F**	**p**
Numbers and algebra	Between groups	64.26	2	32.12		
	Within groups	2005.1	528	1.89	16.93	<0.001
Geometry and measurement	Between groups	694.4	2	347.20		
	Within groups	3448.8	528	3.26	106.41	<0.001
Data	Between groups	536.49	2	268.24	68.40	<0.001
	Within groups	4145.33	528	3.92		

The table indicates a significant difference in students' performance across the different strands. The analysis reveals that primary 2 students outperformed their counterparts in questions on geometry and measurement. Primary 1 students 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 students and 37.3% of primary 3 students. In measurement and geometry questions, primary 2 students 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 students did better 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.

Conclusion

After a successful seven-week period involving the development of materials, co-creation of lesson plans, and review of lesson observations, the results from the endline data indicate variations in students' performances based on gender, school location, and grade level. The findings reveal that students' performance improved in all three strands: numbers and algebra, geometry and measurement, and data. This study demonstrates that the co-creation approach significantly enhanced students' problem-solving abilities, particularly non-routine ones, and fostered a positive mathematical mindset. The collaborative environment established through co-creation with teachers and researchers encouraged active participation, creativity, and a deeper understanding of mathematical concepts. Teachers acknowledged the benefits of this approach, advocating for more such programs, which they believe will lead to improved performance and confidence among students. The iterative co-creation process also empowered teachers to take ownership of their lesson plans and teaching resources, resulting in a more meaningful and engaging teaching experience characterized by greater confidence.

These findings imply that educators should consider integrating co-creation methods into their teaching practices to create a more collaborative and supportive learning environment. Further research could investigate the long-term effects of co-creation among teachers and students, aiming to empower students to become more confident and take ownership of their learning. In conclusion, co-creation is a valuable strategy for enhancing students' problem-solving skills and fostering a growth-oriented mathematical mindset. It ultimately contributes to better teaching experiences and academic success for students.

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Appendix A: Ethics Approval Letter

UNIVERSITY OF GHANA
ETHICS COMMITTEE FOR THE HUMANITIES (ECH)
P. O. Box LG 74, Legon, Accra, Ghana

My Ref. No: ECH 157/ 23-24

February 15, 2024

Professor Ernest Ampadu
Department of Learning
KTH-The Royal Institute of Technology
Brinellvägen 68
11428 Stockholm, Sweden

ETHICAL CLEARANCE
(ECH 157/ 23-24)

The Ethics Committee for the Humanities (ECH) conducted a full-board review and approved your protocol titled:

IMPROVING PUPILS' PROBLEM-SOLVING COMPETENCIES AND MATHEMATICAL MINDSET THROUGH CO-CREATION

PRINCIPAL INVESTIGATOR: **PROFESSOR ERNEST AMPADU**

Please note that the final review report must be submitted to the Committee at the completion of the study. Your research records may be audited at any time during or after the implementation. Any modification of this research project must be submitted to ECH for review and approval prior to implementation.

Please report all serious adverse events related to this study to ECH within seven (7) days verbally and in writing within fourteen (14) days.

This certificate is valid until February 14, 2025. You are required to submit annual reports for continuing review.

Please accept my congratulations.

Yours Sincerely,

ADarkwah

Professor Akosua K. Darkwah
ECH Vice-Chair

Cc: Dr. Rita Yeboah, Department of Teacher Education, UG
Dr. Millicent Narh-Kert, Department of Teacher Education, UG

Tel: +233-303933866 Email: ech@ug.edu.gh

Appendix B: Ghana Education Service Approval Letter 1

GHANA EDUCATION SERVICE

In case of reply the number and date of this Letter should be quoted.

Shai Osudoku District Office
Post Office Box 45
Dodowa

REPUBLIC OF GHANA

My Ref. No.: GES/SOD.1/40/V.3/40
Your Ref. No.:

11th January, 2024

DR. RITA YEBOAH
UNIVERSITY OF GHANA
COLLEGE OF EDUCATION
DEPARTMENT OF TEACHER EDUCATION

RE: PERMISSION TO ENGAGE PRIMARY 1-3 PUPILS AND TEACHERS IN A RESEARCH STUDY

We write to inform you of the receipt of your letter on the above subject and grant you permission to conduct a research titled '***Improving Pupils' Problem – Solving Competencies and Mathematical Mindset through Co-Creation.***

The following are the selected schools.

S/N	NAME OF SCHOOL	CIRCUIT	LEVEL
1	Asebi D/A Basic	Doryumu	Basic
2	Ayikuma R/C Basic	Dodowa East	"
3	Agomeda Presby Basic	Doryumu	"
4	Agomeda D/A Basic	Doryumu	"
5	Doryumu D/A Basic A	Doryumu	"
6	Doryumu D/A Basic B	Doryumu	"
7	Kordiabe R/C Basic	Doryumu	"
8	Asutsuare Junction D/A Basic	Asutsuare Junction	"
9	Manya Jorpanya D/A Basic	Doryumu	"
10	Luom Presby Basic	Asutsuare Junction	"

We wish you a successful exercise.

....

MS. HARRIET LOMOTEY
DIRECTOR OF EDUCATION
SHAI-OSUDOKU DISTRICT
DODOWA

Cc: The SISOs – Doryumu, Dodowa East & Asutsuare Junction
Personal/Subject File

Appendix C: Ghana Education Service Approval Letter 2

GHANA EDUCATION SERVICE

In case of reply, the number and date of this *Letter should be quoted:*

My Reference: **GES/GAR/AdM./ 3 Vol. 4**
Your Ref. No……………………………………

Telephone: +233 (0) 302984099
E- mail: adentanmunicipal@ges.gov.gh

Republic of Ghana

Adentan Municipal Education Office
Post Office Box AD 2326
Adentan – Accra

22nd January, 2024

DR. RITA YEBOAH
UNIVERSITY OF GHANA
COLLEGE OF EDUCATION

RE: PERMISSION LETTER

Permission is granted you to engage Primary 1-3 pupils and teachers in the Adentan Municipality to conduct a research on 'Improving Pupils' Problem – Solving Competencies and Mathematical Mindset Through Co-Creation'.

The research aims to help develop appropriate teaching and learning methods in Mathematics for an interactive teaching and learning experience through co-creation among teachers.

Kindly ensure that the program does not interrupt with Instructional Hours.

Thank you.

…………………………

GIFTY MUSSEY (MS)
DIRECTOR OF EDUCATION
ADENTAN MUNICIPAL

cc: The Frontline, DDs, AdMEO
The SISOs, AdMEO, Adentan

Appendix D: Ghana Education Service Approval Letter 3

GHANA EDUCATION SERVICE

In case of reply the number and date of this Letter should be quoted

Shai Osudoku District Office
Post Office Box 45
Dodowa

REPUBLIC OF GHANA

My Ref No. GES/SOD.1/40/V.3/41
Your Ref No.:

11th January, 2024

DISTRIBUTION:
ALL SCHOOLS CONCERNED

PERMISSION TO ENGAGE PRIMARY 1-3 PUPILS AND TEACHERS IN A RESEARCH STUDY

We write to inform you that, Dr. Rita Yeboah of the Department of Teacher Education, University of Ghana has been granted permission to engage pupils and teachers of primary 1-3 in a research titled ***'Improving Pupils' Problem-Solving Competencies and Mathematical Mindset through Co-Creation.***

Your school has been selected as one of the schools for the exercise.

Kindly offer her the needed assistance, however you must ensure that the exercise does not affect instructional hours negatively.

Thank you.

MS. HARRIET LOMOTEY
DIRECTOR OF EDUCATION
SHAI-OSUDOKU DISTRICT
DODOWA

Cc: Dr. Rita Yeboah - Dept. of Teacher Education, UG ✓
The SISOs - Doryumu, Dodowa East & Asutsuare Junction
File Copy

Appendix E: Problem-Solving Survey

Bio Data

- What is your class?
  - Primary 1
  - Primary 2
  - Primary 3
- Gender
  - Female
  - Male
- What is your age?______________________________

Please indicate how much you agree with each of the following items by rating them on this scale: 1 = strongly disagree; 2 = disagree; 3 = unsure; 4 = agree; 5 = strongly agree.

Please be sure to answer ALL of the questions. Remember, there are no right or wrong answers.

	Statement	**Strongly agree (5)**	**Agree (4)**	**Unsure (3)**	**Disagree (2)**	**Strongly disagree (1)**
1.	I am usually able to think up creative and effective alternatives to solve a problem *when working in groups*.					
2.	I make decisions *with others* and am happy with the outcome.					
3.	When I make plans to solve a problem *with others*, I am almost certain that *we* can make them work.					
4.	Given enough time and effort, I believe I can solve most problems that confront me *when working with others*.					
5.	I trust my ability to solve new and difficult problems *when working with others*.					
6.	When a solution to a problem becomes unsuccessful, I do not work with others to examine why it did not work.					

7.	After I have solved a problem, I do not *work with others to* analyze the outcome.					
8.	When I have a problem, I *work with others to* find possible ways to solve it until we can't come up with any more ideas.					
9.	I try to *work with others to* predict the overall result of carrying out a particular course of action.					
10.	When I am confused by a problem, one of the first things I do is to *work with others to think about* the situation.					
11.	When my first efforts to solve a problem fail, I become sad about my inability to handle the situation.					
12.	Sometimes I do not stop and take time to deal with my problems, but just keep going.					
13.	Even though I work on a problem, sometimes I feel like I am not doing it well.					
14.	I make quick judgments and later regret them.					
15.	Sometimes I get so emotional that I am not able to consider many ways of dealing with my problems.					

Appendix F: Problem-Solving Assessment Tool (Primary 1)

Primary 1

Bio Data

Gender

Female ☐

Male ☐

What is your age? ______________________

Instructions:

Read each question carefully and write down your answers in the boxes.

1. **Ama has 13 apples and got 8 more. How many apples does she have in total?**

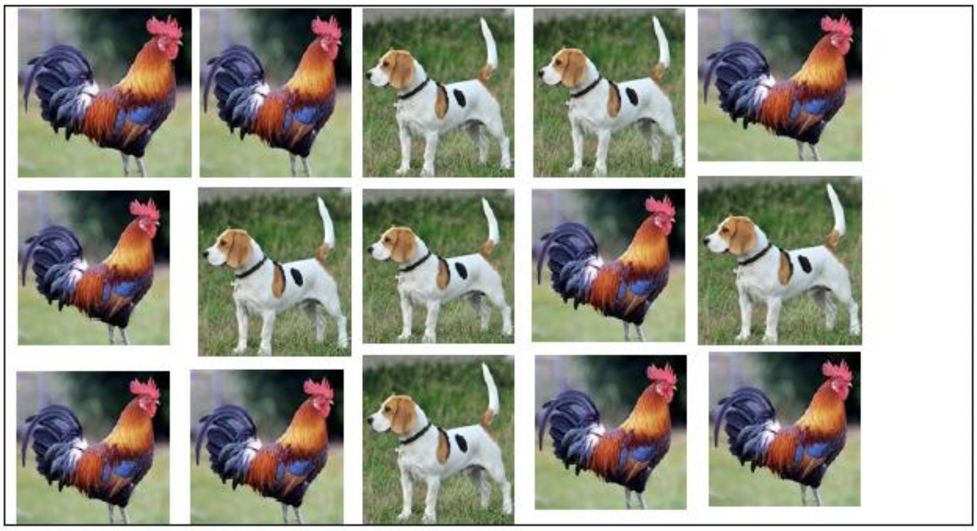
☐

2. **Kofi has 15 oranges and gives 6 to his friend. How many does he have left?**

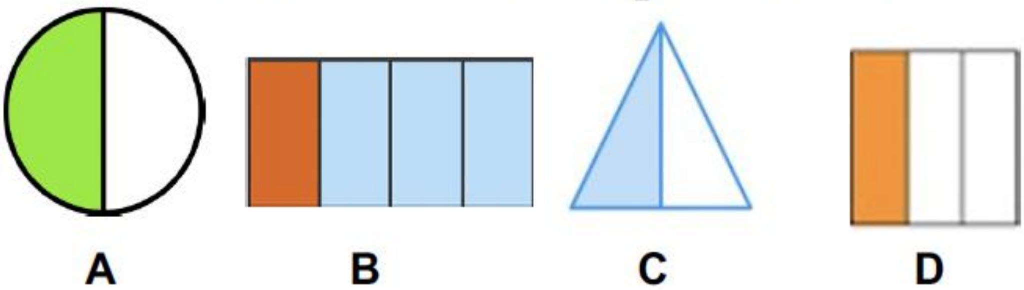
☐

3. **Identify and write the 2D shapes that can be found on the surfaces of the following 3D objects.**

4. **How many more dogs do we need in the box below to get equal number of dogs and chickens?**



5. **Which shape(s) has/have half ($\frac{1}{2}$) of it shaded?**



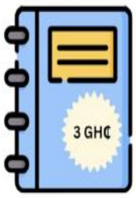
Appendix G: Problem-Solving Assessment Tool (Primary 2)

Instructions:

Read each question carefully and write down your answers in the boxes.

1. **Ama has 3 bags. Each bag has 5 oranges. How many oranges does she have altogether?**

2. **You have 20 Ghana Cedis. How much money will you have left if you buy 2 books and 3 pencils?**



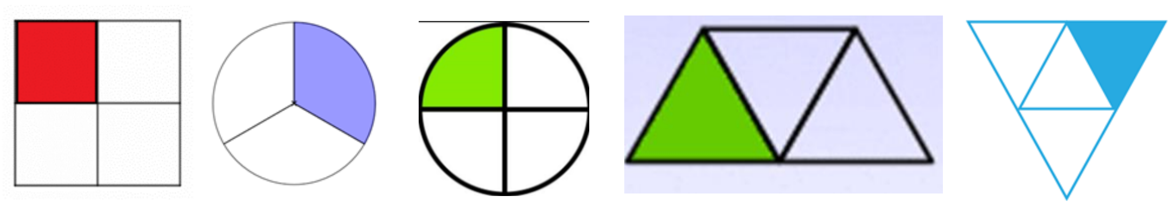
3. **Rita, Millicent, and Ernest are playing a game. The table shows the number of times each has won the game.**

Name	Number of wins
Rita	14
Millicent	17
Ernest	13

a. How many games did they play altogether?

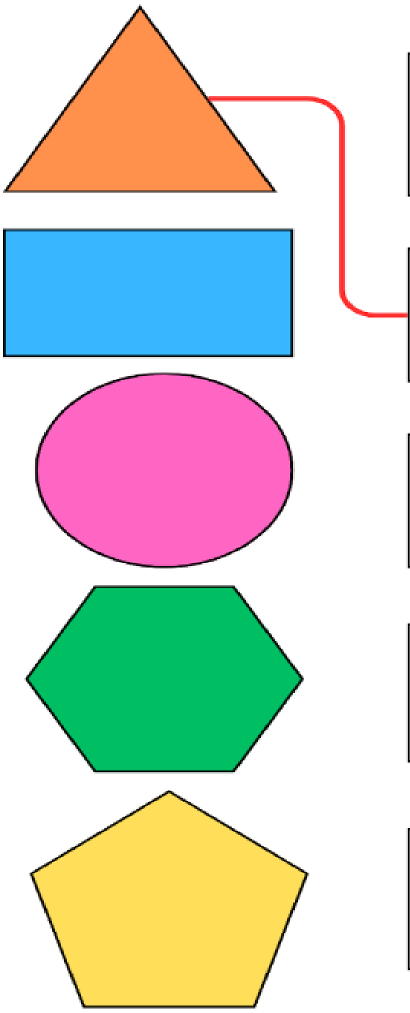
b. How many wins did Millicent get more than Ernest?

4. Identify the fraction(s) representing one-fourth from the pictures below.



A B C D E

5. Match the following shapes with the descriptions.



Zero corners and zero sides

Three corners and three sides

Five corners and five sides

Six corners and six sides

Four corners and four sides

Appendix H: Problem-Solving Assessment Tool (Primary 3)

Instructions:

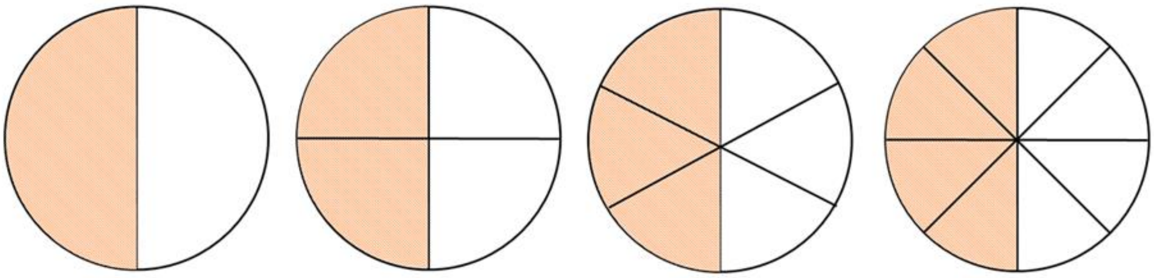
Read each question carefully and write down your answers in the boxes.

1. **Kofi collects 167 counters. Ama collects 149 counters. How many counters do they have altogether?**

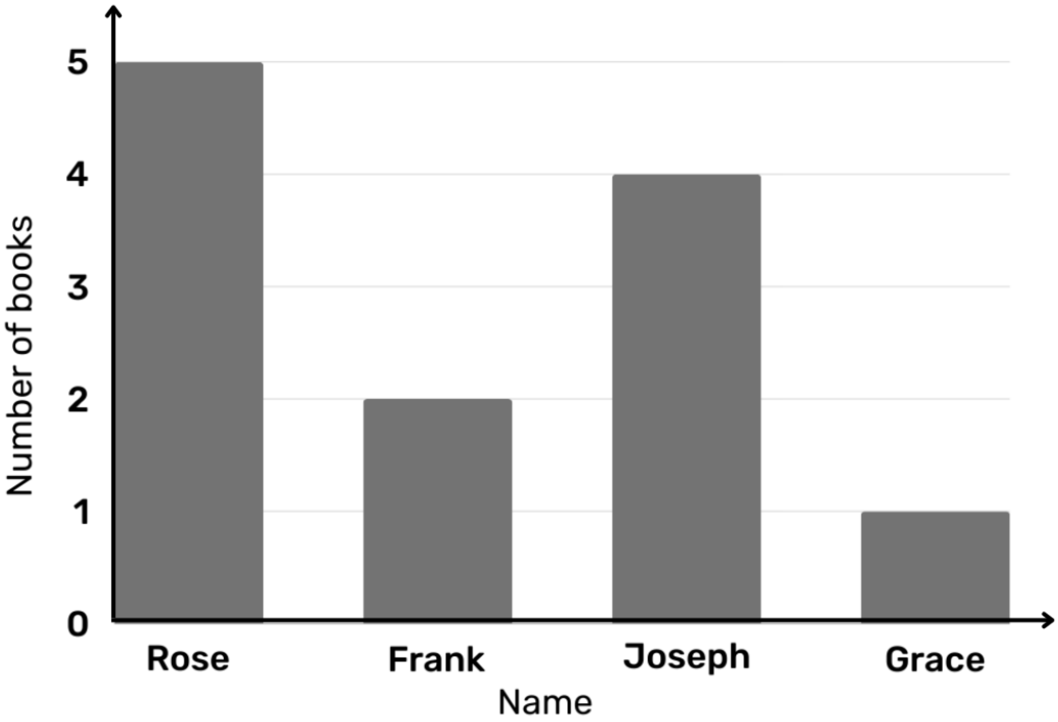
2. **a) Akosua has 53 oranges. She gives 21 oranges to her sister. How many oranges are left?**

   b) There are 38 pieces of fruit in a basket. 11 are apples, 17 are pears, and the rest are oranges. How many oranges are there?

3. **What fractions of the figures below are shaded?**



4. Rose's class records the number of books some students have, as shown in the graph below.



a) How many books does Grace have?

b) How many more books does Rose have than Frank?

c) How many more books does Joseph need to get the same number of books as Rose?

5. **a) A square is 9cm long. What is the total distance (perimeter) around the square?**

5b) The jug below is filled with orange juice. How much orange juice would there be in 3 jars?