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# Bridging Abstract Formulas and Real-World Applications: Developing Grade 10 Learners' Conceptual Understanding of Cylinders in South African Mathematics Classroom

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## Abstract

Calculating the total surface area of a cylinder requires learners to coordinate concepts, representations, and procedures, yet classroom instruction may remain detached from contexts in which mathematical knowledge can be applied. Although real-world applications are widely promoted to contextualize mathematics learning, limited evidence has examined how such interventions influence Grade 10 learners' surface-area performance and learning experiences in an Eastern Cape school. This study investigated changes in Grade 10 learners' performance in calculating the total surface area of a cylinder following a real-world application intervention and explored their experiences. A pragmatic mixed-methods approach was employed using a single-group pre-test–post-test design within a case study. The quantitative component involved 39 Grade 10 Mathematics learners who completed pre- and post-tests, while the qualitative component involved nine selected learners representing high-, average-, and low-achievement groups. Qualitative data were generated through semi-structured interviews, classroom observations, and learner documents. Quantitative data were analyzed using descriptive statistics and a paired-samples t-test, whereas qualitative data were analyzed thematically. Post-test performance was significantly higher than pre-test performance, $t(38) = 6.30, p < .001$, with a large effect size (Cohen's $d = 1.01$). Learners reported that real-world contexts, visual representations, model construction, and collaborative activities helped connect surface-area calculations with familiar situations. Interpreted through Kolb's Experiential Learning Theory, the findings suggest that experiential engagement can support mathematical understanding while providing evidence of improved performance and learner experiences, without establishing causal effects.

**Keywords:** Cylinder; Experiential Learning; Mixed Methods; Real-World Applications; Total Surface Area

## Introduction

Geometry develops reasoning about space, measurement, representation and relationships among mathematical objects. Learning cylinder total surface area requires more than recalling a formula: learners must connect a three-dimensional object with its surfaces, measurements and mathematical representations. Qetrani and Achtaich (2022) distinguish procedural from conceptual knowledge, while Boaler (2022) cautions against excessive reliance on memorization. Procedural fluency remains important, but the central concern is connecting procedure with meaning.

Real-world and contextualized mathematics offers one possible response. Van den Heuvel-Panhuizen and Drijvers (2020) argue that realistic situations can provide starting points for formal mathematical ideas; Fraihat et al. (2022) found that situated learning can support Grade 10 mathematical reasoning; and Tessema et al. (2024) reported positive contributions of realist hands-on learning in geometry. However, contextualization does not automatically produce conceptual understanding. González (2017) argues that a context is valuable when it remains connected to the mathematical structure of the task.

Hands-on learning also requires teacher mediation and reflection. Physical models may make geometric relationships visible without explaining why a cylinder's total surface area contains components. Kolb's (1984) Experiential Learning Theory addresses this by describing learning as a cycle of Concrete Experience, Reflective Observation, Abstract Conceptualization and Active Experimentation. Beard and Wilson (2018) likewise emphasize reflection in transforming experience into learning. The present study therefore treats real-world application as a bridge between experience and formal abstraction.

The issue is relevant in South African mathematics education. Mthethwa et al. (2024) found that geometry tasks in selected South African textbooks were predominantly intra-mathematical, whereas realistic mathematics emphasizes connections between learners' experiences and formal ideas (van den Heuvel-Panhuizen & Drijvers, 2020). Earlier Eastern Cape research identified concerning levels of geometric thinking among Grade 10 learners, with most classified at the lowest Van Hiele level (Alex & Mammen, 2012). These findings support investigation of approaches that help learners construct meaning within their educational contexts.

The research problem combines a local difficulty with a broader gap. Grade 10 learners have trouble understanding and calculating cylinder total surface area, while less is known about how a structured experiential sequence can connect concrete cylindrical objects with formal representations in an Eastern Cape classroom. The present study addresses this gap through real-world contexts, visual representations, model construction, measurement, calculation and presentation organized around Kolb's experiential learning cycle.

The 39 participating learners recorded a pre-test mean of $0.004$ and a post-test mean of $0.355, a\ 0.351-$point or $35.1$ percentage-point increase on the $0-1$ scale. The paired-samples t-test indicated a statistically significant difference, $t(38) = 6.30, p < .001$, with a large effect size (Cohen's $d = 1.01$). Qualitative evidence indicated that learners valued familiar objects, visual representations, model construction, collaboration and practical applications.

The study does not assume that real-world applications are superior to conventional instruction. Rather, it examines whether a structured experiential approach provides opportunities to connect concrete experiences with formal geometric knowledge, while recognizing the limitations of a single-school, single-group design.

## Problem Statement

Ideally, geometry teaching should connect formal concepts with meaningful applications and representations. South Africa's Mathematics Teaching and Learning Framework promotes learning-centred classrooms in which learners and teachers discuss and experiment with mathematical ideas (Department of Basic Education [DBE], 2018). Realistic mathematics can also support relevance and understanding (Boaler, 2022; van den Heuvel-Panhuizen & Drijvers, 2020). However, geometry remains challenging in the Eastern Cape. Chiphambo (2024) identified difficulties including limited conceptual understanding and teaching approaches that constrain learners' meaning making. The present study similarly found very low initial performance: the 39 Grade 10 learners recorded a pre-test mean of 0.004. Although research supports contextualized and hands-on approaches, limited context-specific evidence addresses Grade 10 cylinder total surface area in an Eastern Cape classroom. South African geometry textbooks have also been found to contain predominantly intra-mathematical tasks, with contextualization largely absent (Mthethwa et al., 2024). The gap is therefore whether a structured experiential approach can connect physical cylinder properties with formal surface-area calculations. Addressing this problem matters because difficulty with surface area can limit learners' ability to apply geometry beyond routine formula substitution. Familiar objects and practical situations may help connect mathematical concepts with everyday experiences. The study contributes to Sustainable Development Goal 4, particularly Target 4.1 on relevant and effective learning outcomes and Target 4.7 on knowledge and skills supporting sustainable development (United Nations, 2015). The study therefore examined changes in Grade 10 learners' cylinder surface-area performance following a real-world application intervention and explored their learning experiences.

### Aim of the study

The aim of this study was to examine changes in Grade 10 learners' performance in calculating the total surface area of a cylinder following a real-world application intervention and to explore learners' experiences of learning through the intervention in an Eastern Cape school.

### Main research question

What changes occur in Grade 10 learners' performance in calculating the total surface area of a cylinder following a real-world application intervention, and how do learners experience the intervention?

### Sub-research questions

What difference is observed between Grade 10 learners' pre-test and post-test performance in calculating the total surface area of a cylinder following the real-world application intervention?

How do Grade 10 learners experience the use of real-world applications in learning the total surface area of a cylinder?

## The rationale of the study

The rationale was to support meaningful mathematics learning by connecting abstract ideas with practical applications and familiar cylindrical objects.

### Significance of the study

The study provides context-specific evidence that may inform learner-centred teaching of cylinder surface area through familiar objects and practical problem-solving.

## Literature review

### The theoretical-practical disconnect in geometry

The relationship between formal mathematical knowledge and practical application is particularly important in geometry, where learners must coordinate formulas with spatial representations, measurements and object properties. Cylinder total surface area illustrates this challenge because learners must understand what formula components represent. Learning therefore requires a connection between procedural knowledge and conceptual meaning (Boaler, 2022; Qetrani & Achtaich, 2022). Boaler (2022) argues that excessive reliance on memorized procedures can restrict exploration and mathematical connections. Qetrani and Achtaich (2022) similarly show that procedural performance does not necessarily indicate conceptual understanding. A learner may substitute measurements correctly while misunderstanding which surfaces are included. Procedural fluency is therefore most meaningful when linked to mathematical relationships. For cylinder surface area, this means understanding the relationship among radius, height, the curved surface and the two circular bases rather than merely recalling a formula (Qetrani & Achtaich, 2022).

Realistic mathematics education provides a complementary perspective. Meaningful situations can support movement towards formal mathematical ideas (van den Heuvel-Panhuizen & Drijvers, 2020). Situated learning has supported mathematical reasoning among Grade 10 learners (Fraihat et al., 2022), while realist hands-on learning has contributed to conceptual understanding and problem-solving in geometry (Tessema et al., 2024). These findings support contextualized learning, but they do not show that a real-world example automatically produces conceptual understanding. González (2017) argues that context must remain connected to the mathematical structure of the task. Learners therefore need opportunities to analyze objects, discuss observations and connect representations with mathematical relationships.

The literature reports different outcomes: some studies emphasize engagement and motivation (Sitopu et al., 2024; Amalia et al., 2024), while others emphasize reasoning, problem-solving and conceptual development (Fraihat et al., 2022; Tessema et al., 2024). These outcomes are not equivalent. The present study therefore treats learner experiences and measured performance as distinct dimensions. This distinction is relevant in South Africa, where mathematics classrooms vary in socioeconomic, cultural and educational conditions. Meeran and Van Wyk (2022) highlight learners' diverse contexts, while van den Heuvel-Panhuizen and Drijvers (2020) emphasize meaningful contexts for developing mathematical concepts. Familiar cylindrical objects such as cans, drums, pipes and water tanks can help learners explore radius, diameter, circumference, curved surface area and the two circular bases, making the components of the total surface-area formula more tangible. Contextualization is not a universal solution. Resources, teacher knowledge, curriculum demands and classroom conditions may affect implementation, so its value should be examined in actual classrooms.

The literature thus identifies a difficulty in moving between concrete experience, visual representation, mathematical relationships and formal procedures. This conceptualization underpins the present study's use of cylindrical objects, models, representations and formal calculations. This movement is consistent with Kolb's (1984) Experiential Learning Theory. Beard and Wilson (2018) emphasize reflection in transforming experience into learning, while Felder and Brent (2024) highlight active learning and conceptual understanding in STEM education.

## Real-world applications and conceptual understanding in geometry

Real-world mathematics should involve more than replacing an abstract question with a familiar object; learners should interpret, represent, measure or solve meaningful problems (van den Heuvel-Panhuizen & Drijvers, 2020). Contextualized learning can support engagement and mathematical understanding. Sitopu et al. (2024) emphasize meaningful situations for mathematical literacy, Amalia et al. (2024) report value in contextual approaches, and Fauziah (2020) found that relating, experiencing, applying, cooperating and transferring supported mathematical problem-solving. Geometry-specific evidence is also positive: situated learning supported Grade 10 mathematical reasoning (Fraihat et al., 2022), while realist hands-on learning contributed to conceptual understanding and problem-solving in geometry (Tessema et al., 2024). Nevertheless, contextualization is not automatically effective; the context, task, teacher mediation, discussion and reflection influence learning. A real-world object alone does not establish conceptual understanding.

In the present study, cylindrical objects were used in activities requiring measurement, model construction, surface identification, calculation and explanation. The intervention comprised digital simulation, model construction, and calculation and presentation activities. The sequence moved learners among representations: simulation showed component surfaces, model construction provided a concrete representation, measurement linked dimensions to quantities, and calculation linked experience to formal procedures. Everyday cylindrical objects were relevant to the Eastern Cape context because they connected mathematical concepts with objects learners may encounter outside school (Meeran & Van Wyk, 2022; van den Heuvel-Panhuizen & Drijvers, 2020).

The study does not assume identical effects across schools. Its 39-learner, single-school case provides context-specific rather than broadly generalizable evidence. Real-world application is conceptualized as a process between experience and abstraction: learners encounter a concrete situation, reflect, develop formal representations and apply them to related problems. This supports Kolb's (1984) Experiential Learning Theory.

### Misconceptions and conceptual understanding of cylinder surface area

A further theme concerns misconceptions in geometric measurement taught predominantly through procedures. Total surface area requires coordination of radius, diameter, circumference, area and the surfaces of a three-dimensional object. Qetrani and Achtaich (2022) show that procedural competence may coexist with conceptual difficulty. In cylinder surface area, remembering the formula does not necessarily mean understanding its components. Misconceptions may include confusing surface area with volume, lateral with total surface area, radius with diameter, or omitting the two circular bases. Such errors may indicate an incomplete representation of the object.

Hands-on learning may help address these difficulties. Tessema et al. (2024) found contributions of realist hands-on learning to geometry, while van den Heuvel-Panhuizen and Drijvers (2020) emphasize meaningful situations for developing mathematical concepts. However, manipulation alone does not eliminate misconceptions. Learners need opportunities to observe, question, discuss, represent and explain their experience mathematically. This strengthens the relevance of Kolb's (1984) model: concrete experience should be followed by reflection, conceptualization and application. Beard and Wilson (2018) similarly emphasize reflection in meaningful learning.

## Theoretical framework: experiential learning theory

This study is underpinned by Kolb's Experiential Learning Theory (ELT), which views learning as knowledge creation through transforming experience (Kolb, 1984). Its four modes are Concrete Experience (CE), Reflective Observation (RO), Abstract Conceptualization (AC) and Active Experimentation (AE). Beard and Wilson (2018) similarly emphasize reflection, interpretation and application. Kolb's theory guided intervention design and interpretation. Learners encountered cylindrical objects, reflected on observations and errors, connected these experiences with mathematical concepts, and applied their developing understanding through calculation and presentation.

### Concrete Experience

CE involves direct interaction with a task (Kolb, 1984). Learners interacted with cylindrical objects and models, constructed familiar objects such as cans and drums, measured dimensions and used a digital simulation showing a cylinder as two circles and a rectangle. Evidence came from observations, models, worksheets and interviews.

The purpose was to make the cylinder's structure visible before reliance on formal formulae. These activities supported recognition of the cylinder's surfaces and measurable dimensions. Evidence included classroom observations, learner models, worksheets and interview accounts concerning participation and use of manipulatives.

### Reflective Observation

RO involves examining experience to identify patterns and difficulties (Kolb, 1984). It was operationalized through group discussions, examination of errors, comparison of measurements and discussion of the cylinder's surfaces.

Learners considered observations from models and simulations and discussed calculation errors and their possible causes. Nine learners three high achievers, three average achievers and three low achievers, provided qualitative evidence through interviews, observations and learner documents. Reflection was particularly relevant to pre-test misconceptions because it allowed learners to reconsider the components of total surface area.

### Abstract Conceptualization

AC occurs when observations and reflections become concepts or explanations (Kolb, 1984). Here, it represented movement from physical and visual properties towards formal mathematical understanding. Learners connected cylindrical objects and models with relationships among the curved surface, two circular bases, radius and height. Evidence came from calculations, worksheets, post-test responses and interview accounts. These sources were considered together because test performance alone may not demonstrate conceptual understanding (Qetrani & Achtaich, 2022). Improvement in performance was therefore interpreted alongside qualitative evidence about learners' explanations and experiences.

### Active Experimentation

AE involves applying concepts to test and refine understanding (Kolb, 1984). It was operationalized through calculation, application and presentation activities based on cylindrical objects. Learners applied developed relationships to specific objects and communicated their calculations, testing whether the ideas could be used beyond the initial experience. Evidence came from learner calculations, presentations, worksheets, observations and post-test performance.

## Methods

The study was underpinned by a pragmatic paradigm, which prioritizes practical consequences and "what works" in addressing educational challenges (Biesta, 2010; Creswell & Plano Clark, 2018). This supported integration of quantitative performance evidence with qualitative learner experiences.

### Research Paradigm

Pragmatism was appropriate because the study examined both performance changes and experiences during implementation. It recognizes context-dependent realities and values knowledge that can improve practice (Biesta, 2010), while supporting quantitative and qualitative methods.

### Research Approach

The study adopted a mixed-methods approach integrating quantitative and qualitative evidence (Creswell & Plano Clark, 2018; Johnson et al., 2007). The quantitative strand examined changes in cylinder surface-area performance; the qualitative strand explored learner experiences and classroom processes. A sequential mixed-methods design was used within a case study. The quantitative strand followed pre-test, intervention and post-test stages; qualitative data then contextualized the quantitative pattern. Integration occurred through triangulation.

All 39 Grade 10 Mathematics learners completed the pre-test and post-test. The pre-test established baseline performance and difficulties, while the post-test provided evidence following the intervention. The qualitative component involved nine purposively selected learners: three high achievers, three average achievers and three low achievers. Maximum-variation sampling captured experiences across achievement levels. Data came from semi-structured interviews, classroom observations and learner documents. The strands were complementary: quantitative data indicated the extent and statistical significance of performance changes, while qualitative evidence provided contextual information about learner experiences and classroom processes.

### Research design

A case study design bounded the investigation by the Grade 10 cylinder surface-area topic, participating learners and Eastern Cape school setting (Yin, 2018). The case study contextualized assessment results with classroom processes and learner experiences. Mixed methods integrated the evidence, while the case study bounded the classroom investigation.

### Population

The study was conducted in one selected Eastern Cape school and involved 39 Grade 10 Mathematics learners. The population comprised the available Grade 10 Mathematics learners in that setting. The school was purposively selected because it provided access to the Grade 10 context relevant to the study. Using one school created a bounded context for examining the intervention in depth; the design therefore prioritized contextual understanding rather than statistical generalization. All 39 learners completed the pre-test and post-test, enabling comparison of performance before and after the intervention.

Nine learners were selected purposively using maximum-variation sampling: three high achievers, three average achievers and three low achievers. This represented different achievement levels in the exploration of learner experiences. The sampling rationale was linked to the research question because learners with different prior performance could experience the activities differently. The qualitative sample therefore complemented the quantitative evidence within the bounded case-study design.

## Intervention Strategy

The intervention was designed to address Grade 10 learners' difficulties in understanding and calculating the total surface area of a cylinder through the integration of real-world applications, visual representations, hands-on activities, collaborative learning and structured mathematical practice. The intervention consisted of three sequential stages and was followed by the post-test. The sequence was informed by Kolb's (1984) Experiential Learning Theory and was designed to provide opportunities for learners to move from concrete experience, through reflection and conceptualization, to active experimentation.

The intervention did not treat real-world examples simply as introductory illustrations. Instead, learners were required to interact with cylindrical objects and representations, discuss their observations, construct and measure models, connect these observations to mathematical relationships, and apply the resulting knowledge to surface-area problems. The study describes the intervention as incorporating real-world applications, structured practice exercises and timely feedback to address existing knowledge gaps and misconceptions.

## Stage 1: Visual and real-world exploration of cylindrical objects

The first stage provided learners with a concrete and visual introduction to the concept of total surface area. The activities used familiar cylindrical contexts, including water tanks, pipes, cans, fencing and tiling, to establish connections between the mathematical concept and objects or situations outside the textbook. A digital simulation was used to enable learners to observe the surfaces of a cylinder and to visualize the relationship between the three-dimensional object and its exposed surfaces. The simulation helped learners see that the cylinder comprises different surfaces that contribute to its total surface area. The use of visual simulation was particularly important because learners initially experienced difficulties conceptualizing total surface area as an integrated measure.

The teacher's role at this stage was to facilitate learners' observation and questioning, guide attention towards the relevant dimensions and surfaces, and provide clarification and feedback when misconceptions emerged. The instructional approach therefore positioned learners as active participants rather than passive recipients of a formula. Group discussion and questioning were used to encourage learners to compare observations and explain their thinking. The study reports that regular questioning and feedback were used to identify and address misconceptions during the activities.

### Materials and learner tasks

The main learning resources at this stage were digital simulation/visualization, real-world cylindrical examples, visual representations of cylindrical surfaces, teacher-guided questions, and group discussion and problem-solving activities. Learners were expected to identify the surfaces of the cylinder, observe how the surfaces could be represented, discuss the dimensions required for calculation, and relate the mathematical problem to familiar objects.

### Relationship with Kolb's learning cycle

This stage primarily represents CE because learners encountered the mathematical concept through direct visual and contextual experiences. It also initiated RO because learners were encouraged to discuss what they observed, ask questions and compare their interpretations. Kolb (1984) argues that concrete experience provides the basis from which learners can reflect and construct meaning. Evidence of this stage was obtained through classroom observations and learner accounts, which recorded learner participation, interaction with manipulatives and engagement with everyday objects.

### Stage 2: Construction and measurement of cylindrical models

The second stage provided a more direct hands-on experience through the construction and measurement of physical cylindrical models. Learners worked collaboratively to construct models and examine their physical dimensions. This activity enabled them to interact directly with the structural components of a cylinder rather than encountering those components only through diagrams or symbolic formulae. The purpose of the activity was to establish a relationship between the physical dimensions of the model and the mathematical quantities required to calculate total surface area. Learners measured dimensions of the models and considered how the different surfaces contributed to the overall surface area. The hands-on activity therefore provided an opportunity to make the abstract concept more tangible.

The teacher's role during this stage was primarily facilitative and supportive. Rather than completing the construction or calculations for learners, the teacher monitored group activities, asked questions, clarified misunderstandings and provided timely feedback. This role was consistent with the intervention's emphasis on structured group work, manipulation of physical materials and learner participation. The study reports that observations focused on learner participation, interaction, use of manipulatives and connections with everyday objects.

### Materials and learner tasks

The materials included physical cylindrical models, materials used for constructing the models, measuring tools, learner worksheets, and writing and calculation materials. Furthermore, learners were required to construct or examine a cylindrical model, identify its relevant surfaces, measure the required dimensions, discuss the meaning of the measurements, connect the measurements to the components of the surface-area calculation, and record their observations and calculations.

The constructed models and worksheets subsequently became part of the documentary evidence used in the study. The study specifically indicates that learner worksheets, constructed cylinder models and test scripts were reviewed to trace the development of conceptual understanding.

## Relationship to Kolb's learning cycle

This stage represents CE more strongly because learners physically interacted with and constructed representations of the mathematical object. It also provided opportunities for RO as learners discussed measurements, compared approaches and considered errors. The stage further initiated AC, because learners began connecting their physical observations to mathematical relationships. Kolb (1984) describes this movement from experience and reflection towards conceptualization as a central part of experiential learning.

The qualitative evidence supports this interpretation. Classroom observations indicated that learners actively interacted with physical models and manipulatives, while group discussions and collaborative problem-solving provided opportunities for learners to question and refine their understanding.

## Stage 3: Calculation, application and learner presentation

The third stage moved learners from physical and visual experiences towards formal mathematical calculation and application. Learners used the information obtained from their models and activities to calculate total surface area and solve related problems. They subsequently presented their calculations and findings.

This stage was important because the purpose of the intervention was not simply to provide learners with enjoyable practical experiences. Learners were required to translate those experiences into formal mathematical reasoning and demonstrate that they could apply the concept of total surface area.

The teacher continued to act as a facilitator and provider of feedback, monitoring learners' calculations, identifying errors and prompting learners to reconsider their reasoning rather than simply supplying answers. Group problem-solving and learner-led presentations provided opportunities for learners to explain their mathematical reasoning to peers.

## Materials and learner tasks

The learning resources at this stage included constructed cylindrical models, learners' measurements, worksheets, mathematical formulae and calculation procedures, practical problem-solving tasks, and presentation materials. Furthermore, learners were required to use the dimensions obtained from their models, identify the relevant components of the cylinder, calculate the total surface area, compare or discuss their solutions within groups, identify and correct errors following feedback, and present their calculations and explanations to others.

The study identified learner-led presentations, structured group work, manipulatives and digital tools as important instructional strategies because they provided opportunities for experimentation, feedback and refinement of understanding.

## Relationship with Kolb's learning cycle

This stage primarily represents AC and AE. Learners moved from their physical and visual observations to the formal mathematical representation of total surface area and then tested that understanding by applying it to calculations and practical problems. The post-test findings provide evidence of the extent to which learners could subsequently apply the concept. Questions 3 and 4 produced relatively high correct-response rates of 92.30% and 90%, respectively, whereas Questions 1 and 5 remained more difficult, with 33.33% and 25.64% correct responses. This variation is important because it suggests that the transition from experience to formal application was not equally successful across all aspects of the concept.

## Alignment of the Three Intervention Stages with Kolb's Experiential Learning Cycle

The three intervention stages were therefore not intended to correspond mechanically to one stage of Kolb's cycle. Rather, they were designed to create opportunities for learners to move through the cycle progressively, with some activities addressing more than one stage.

**Table 1.** Operationalization of Kolb's cycle in the intervention

| Intervention stage | Main learner activity | Teacher role | Materials/evidence | Kolb stage |
|---|---|---|---|---|
| Stage 1: Visual and contextual exploration | Examine real-world cylindrical situations; use digital simulation; identify surfaces and dimensions; discuss observations | Facilitate observation, questioning and discussion; identify misconceptions; provide feedback | Digital simulation, visual representations, real-world examples, observation records | Concrete Experience → Reflective Observation |
| Stage 2: Model construction and measurement | Construct/examine cylindrical models; measure dimensions; identify surfaces; discuss measurements | Facilitate group work; guide measurement; question learners; provide feedback | Cylindrical models, measuring tools, worksheets, observations | Concrete Experience → Reflective Observation → Abstract Conceptualisation |

| | | | | |
|---|---|---|---|---|
| Stage 3: Calculation and presentation | Apply measurements to calculate total surface area; solve problems; discuss and present solutions | Monitor reasoning; provide feedback; challenge errors; facilitate presentations | Models, measurements, worksheets, calculations, presentations | Abstract Conceptualisation → Active Experimentation |

This alignment is consistent with this study's description of the intervention and its findings. The study reports that visual simulations supported spatial reasoning, physical models promoted active learning, and learner presentations supported articulation and peer learning.

## Evidence of the Experiential Learning Cycle

The intervention generated evidence corresponding to the four stages of Kolb's cycle through multiple data sources. CE was evidenced through learners' interaction with physical models, digital simulations and real-world cylindrical objects. RO was evidenced through learner discussions, questioning, examination of errors and interview accounts concerning their experiences. AC was evidenced through learners' explanations of the surface-area formula, identification of curved and flat surfaces, worksheets and mathematical calculations. AE was evidenced through learners' application of the formula to practical problems, group problem-solving, presentations and post-test performance.

The qualitative findings provide further support for this interpretation. Learners reported that familiar contexts helped them make sense of the mathematical content, while classroom observations showed questioning, discussion of errors and comparison of problem-solving approaches. Learners also demonstrated an ability to explain the surface-area formula in their own words and distinguish between curved and flat surfaces, although difficulties remained in tasks requiring the integration of multiple surface components.

These findings are important because they show that the intervention was not simply "hands-on". Its design created a progression from experiencing the geometric object, to reflecting on it, to developing a mathematical explanation, and finally to applying that explanation. This progression is consistent with Kolb's (1984) experiential learning cycle.

## Teacher's Role Across the Intervention

The teacher's role changed from facilitator of experience to facilitator of conceptualization and application across the three stages. During the initial stage, the teacher guided learners' attention towards the relevant features of the cylinder and encouraged observation and questioning. During model construction, the teacher facilitated collaborative activity, monitored learners' measurements and provided feedback. During calculation and presentation, the teacher supported mathematical reasoning, challenged errors and facilitated learners' explanations.

This role is consistent with the study's broader learner-centred orientation. The teacher did not remove mathematical structure or formal instruction; rather, formal mathematical knowledge was introduced in connection with learners' experiences and observations. This distinction is important because experiential learning does not imply that teachers should withdraw from instruction. Instead, the teacher provides the structure, questions, feedback and conceptual guidance necessary for learners to transform experience into mathematical knowledge (Kolb, 1984; Beard & Wilson, 2021).

## Quantitative and Qualitative Data Analysis

The analysis of data followed a mixed-methods approach, integrating quantitative and qualitative techniques to provide a comprehensive understanding of the research problem. Quantitative data from the pre-test and post-test were analyzed using PSPP statistical analysis software, release 1.2.0-g0fb4db. Descriptive statistics, including frequencies, percentages and mean scores, were used to establish learners' baseline performance and identify persistent misconceptions. A paired-samples t-test was conducted at the 0.05 level of significance to determine whether the difference between pre-test and post-test performance was statistically significant. Cohen's d was calculated to assess the magnitude of the observed change, and a 95% confidence interval was used to estimate the precision of the mean difference. The assumptions of paired observations, independence between learners, approximate normality of the difference scores and absence of influential outliers were also considered. The analysis produced a statistically significant difference, $t(38) = 6.30, p < .001$, with a mean difference of 0.351 and a large effect size (Cohen's $d = 1.01$).

Qualitative data from semi-structured interviews, classroom observations and document analysis were analyzed thematically. The analysis followed an iterative six-stage process involving familiarization with the data, generation of initial codes, searching for themes, reviewing themes, defining and naming themes, and producing the final analysis (Braun & Clarke, 2021). The researcher compared emerging codes and themes across the different data sources and used relevant learner quotations and documentary evidence to support the interpretation.

Saturation was considered during the iterative analysis, particularly in assessing whether successive interviews generated substantially new codes or themes. However, because the study did not document a formal saturation assessment, the findings are more appropriately described as achieving qualitative data sufficiency rather than claiming definitive theoretical saturation. The nine interview participants were selected through maximum-variation sampling and represented high-, average- and low-achievement groups, while observations and learner documents provided additional sources of evidence.

The quantitative and qualitative findings were subsequently integrated through triangulation and interpretation. Quantitative results provided evidence of changes in learner performance, while qualitative evidence provided contextual insight into learners' experiences, engagement and learning processes. The integrated findings were interpreted in relation to Kolb's ELT (1984), particularly the stages of concrete experience, reflective observation, abstract conceptualization and active experimentation. This approach enabled the study to connect measurable changes in performance with evidence concerning how learners experienced and engaged with real-world intervention within the Eastern Cape context.

## Results

### Quantitative results

The pre-test results indicated very limited initial performance in calculating the total surface area of a cylinder. Among the 39 learners who completed both assessments, the mean pre-test score was $0.004$ $(SD = 0.016)$, compared with a post-test mean of $0.355$. The mean difference between the two assessments was $0.351$, with a $95\%$ confidence interval of $[0.238, 0.464]$. A paired-samples t-test indicated that the difference between pre-test and post-test scores was statistically significant, $t(38) = 6.30, p < .001$. The magnitude of the difference was large, with a Cohen's d of 1.01.

The 0.351 mean difference should be interpreted as a 35.1 percentage-point increase on the $0 - 1$ scoring scale, rather than as a $35.1\%$ relative improvement. This distinction is important because the pre-test mean was very close to zero; expressing the change as a relative percentage would produce a disproportionately large value and could be misleading. The results therefore indicate a substantial improvement in learners' mean assessment performance following the intervention.

However, the findings should be interpreted cautiously. The study used a single-group pre-test–post-test design and did not include a control or comparison group. Consequently, although the statistically significant difference demonstrates that learners performed better on the post-test than on the pre-test, the analysis cannot establish that the real-world intervention alone caused the improvement. Other factors, such as normal learning progression, exposure to the assessment content, practice effects, or other classroom influences, may also have contributed to the observed change.

The quantitative findings therefore provide evidence of a significant improvement in learner performance following the intervention, rather than definitive evidence of causal effectiveness. This interpretation is consistent with the study's case-study and mixed-methods design and provides an appropriate basis for considering the qualitative evidence concerning learners' experiences of intervention.

### Qualitative Findings

Analysis of the semi-structured interviews, classroom observations and learner-produced documents generated four themes: (1) real-world application enhances learning, (2) engagement and perceived interest through contextual learning, (3) perceived practical application of mathematical knowledge, and (4) active, visual and collaborative learning approaches. The themes were developed from recurring patterns in the interview data and were supported by classroom observations and learner work. Nine learners participated in the interviews, representing high-, average- and low-achievement groups.

### Theme 1: Real-world application enhances learning

The first theme concerned learners' perceptions that real-world applications helped them connect the formal concept of total surface area with familiar situations. The theme was supported by 17 interview annotations, including references to adjusting tank sizes, fencing, tiling, drum measurements, water drains and stands, as well as connections between mathematics and careers such as architecture and plumbing.

For example, L3 explained:

"Maybe at home I'm installing a tank, but it seems too big for the given space, as a learner, I know what the calculation is needed to adjust to that situation."

This quotation illustrates the movement from classroom calculation to practical application. Similarly, L6 stated:

"The knowledge gained can help me with fencing in the garden or tiling."

The raw responses therefore linked the code "application to everyday situations" with the broader theme of real-world application enhancing learning. Classroom observations provided complementary evidence: learners actively engaged with cylindrical objects, manipulatives and digital tools and made connections between theoretical content and practical situations.

The evidence suggests that learners perceived the contextual examples as helping them understand the practical meaning of surface-area calculations. However, these qualitative perceptions are interpreted as evidence of perceived relevance and application, rather than as independent proof of conceptual improvement.

### Theme 2: Engagement and perceived interest through contextual learning

The second theme concerned learners' increased interest and participation when mathematics was presented through familiar and practical contexts. This theme emerged from 10 interview annotations, including descriptions of the activities as engaging, enjoyable, helpful and memorable. Learners also identified projects and group activities as contributing to their involvement.

L1 captured this perception directly:

"It helps us as learners... because it relates the mathematical concepts to our everyday life."

A longer account from L8 provides further evidence:

"Yes Ma'am, it was more interesting and engaging. When we used real items and did activities like building our own models, I felt more involved. I didn't get bored like in normal lessons because we were doing things ourselves and working together.

These responses were supported by classroom observations. Learners frequently asked questions-initiated discussions and proposed problem-solving strategies during individual and group activities. The raw observational evidence therefore supports the interpretation that the contextual activities were associated with active participation rather than merely positive verbal perceptions.

The findings should nevertheless be interpreted cautiously. Learners' reports of enjoyment and increased engagement demonstrate their perceptions of the learning experience; they do not independently establish increased mathematical achievement. The quantitative results provide separate evidence concerning changes in assessment performance.

### Theme 3: Perceived practical application of mathematical knowledge

The third theme concerned learners' perceptions that the intervention enabled them to apply mathematical knowledge beyond the immediate classroom task. The theme included annotations concerning materials estimation, painting, wiring, engineering, independence and critical thinking.

L8 expressed this connection between mathematical learning and practical use:

"I now understand how the formula works in real life."

Similarly, L9 connected the practical activities with collaborative learning:

"We were also allowed to work in groups and build models."

A further example came from L8, who described possible applications involving painting, garden fencing and covering pipes:

"It can help in many ways. Like, if I ever need to calculate how much paint to use on a round water tank, I'll know how to do it."

These statements were complemented by observation evidence showing that learners completed the assigned tasks, explained the surface-area formula in their own words and connected theoretical content with practical situations.

The evidence therefore suggests that learners perceived the intervention as providing opportunities to apply and communicate mathematical knowledge in practical situations. These findings are interpreted as perceived practical relevance rather than evidence of long-term transfer of skills, which was not independently measured in the study.

### Theme 4: Active, visual and collaborative learning approaches

The fourth theme focused on the contribution of physical models, digital tools and collaborative activities to learners' engagement with three-dimensional geometry. The interview annotations specifically identified cans and pipes as useful visual objects, model construction as supporting spatial understanding, and group discussions as contributing to understanding.

L9 described the value of these activities:

"We were also allowed to work in groups and build models, and that made the lesson more exciting. It was not just the teacher talking, but we were also doing the work ourselves."

This quotation provides a direct link between the raw data and the theme: group work + model construction + learner participation → active, visual and collaborative learning.

Observation data further showed that learners used manipulatives and digital tools to visualize three-dimensional shapes, asked questions, participated in discussions and shared problem-solving strategies. These observations provide an important second source of evidence for the theme and reduce reliance on learner self-report alone.

The findings are also consistent with the intervention design, which incorporated digital simulation, physical model construction, measurement, calculation and learner presentations. These activities provided opportunities for learners to experience the cylinder concretely, reflect on its properties, conceptualize its mathematical relationships and apply those relationships through calculation and explanation.

### Integration of Qualitative Evidence

Across the four themes, the qualitative evidence shows a consistent pattern: learners described real-world contexts as making surface area more meaningful, reported greater interest and participation, identified practical applications of mathematics, and valued visual, hands-on and collaborative activities. These perceptions were supported by observations of questioning, discussion, model construction, use of manipulatives and application of mathematical ideas.

The qualitative findings also align with the four stages of Kolb's ELT. Interaction with real-world objects and models provided concrete experience; questioning, discussion and consideration of errors provided opportunities for reflective observation; learners' explanations of surface-area relationships represented abstract conceptualization; and applying calculations to practical situations represented active experimentation.

Importantly, the qualitative evidence does not indicate that all learners achieved complete conceptual understanding. The post-test results showed that Questions 1 and 5 remained difficult for some learners, particularly where several surface components had to be integrated. Thus, the qualitative findings are best interpreted as evidence that learners experienced the intervention as meaningful and engaged actively with the mathematical concept, while the quantitative findings provide separate evidence of changes in measured performance.

## Discussion

The findings indicate that learners' performance in calculating the total surface area of a cylinder improved following the real-world application intervention, while the qualitative evidence suggests that learners experienced the approach as meaningful, engaging, and practical. These findings are consistent with research indicating that realistic and hands-on approaches can support conceptual understanding and problem-solving in geometry (Fraihat et al., 2022; Tessema et al., 2024). However, the contribution of the present study extends beyond confirming these findings. By interpreting the intervention through Kolb's ELT within an Eastern Cape classroom context, the findings provide insight into how the approach may have supported learners' progression from concrete experience toward mathematical abstraction and application.

## Real-world contexts as a bridge between concrete experience and mathematical meaning

The quantitative results showed a significant increase in learners' performance between the pre-test and post-test, with a large effect size. Qualitative evidence helps explain this change. Learners reported that familiar objects such as cans, water tanks, and pipes helped them understand what the surface-area formula represented. For example, L8 explained that working with cans and water tanks helped the learner "see how the formula works in real life." Similarly, L3 connected surface-area calculations to adjusting the size of a water tank, while L6 referred to applications such as fencing and tiling.

These findings support the argument that meaningful contexts can provide an entry point into formal mathematics. González (2017) argues that effective realistic contexts should provide meaningful entry points, connect with learners' experiences, and remain genuinely connected to mathematical content. This is particularly relevant because the cylindrical objects were not merely motivational examples; learners were required to identify their surfaces, measure dimensions, and connect those dimensions to mathematical calculations. Research on realistic hands-on learning in solid geometry similarly found positive effects on conceptual understanding and problem-solving (Tessema et al., 2024).

From Kolb's perspective, these findings can be interpreted as evidence of CE. Kolb (1984) proposes that learning begins with experience that can subsequently be transformed through reflection, conceptualization, and experimentation. Contemporary reviews of experiential learning similarly emphasize that meaningful experiential learning involves active participation in contextually situated experiences followed by reflection and conceptual development. Thus, physical models, digital simulations, and real-world objects provided learners with concrete referents for their mathematical reasoning.

The significance of this finding is therefore not simply that learners were exposed to "real-life examples." Rather, the context changed the representational starting point of the lesson. Instead of beginning exclusively with a symbolic formula, learners first encountered the physical structure to which the formula referred. This may have reduced the conceptual distance between the cylinder as an object and the cylinder as a mathematical representation.

## Reflection and visualization as mechanisms for conceptual development

The findings further indicate that concrete experience alone was not sufficient. Learners asked questions, discussed errors, compared solutions, and used digital and physical representations to examine the surfaces of cylinders. This evidence corresponds to the RO stage of Kolb's cycle.

Kolb's framework proposes that experience becomes learning through transformation, with reflection allowing learners to examine their experiences before developing more abstract understandings (Kolb, 1984). Evidence from experiential-learning research similarly identifies critical reflection as an important mediator between experience and meaningful learning.

In the present study, reflection appears to have occurred through questioning, group discussion, examination of errors, and comparison of different problem-solving approaches. This provides a possible explanation for why the intervention extended beyond a hands-on activity. Learners were not simply manipulating models; they were required to consider what the models represented.

The digital simulation appears to have played a complementary role by making the structure of the cylinder visible. Learners could connect the three-dimensional object with its component surfaces and subsequently with the formula. This is particularly important for surface area because the conceptual difficulty lies partly in understanding that total surface area comprises different surfaces that must be integrated into one mathematical measure.

## From experience to abstract conceptualization

The qualitative findings provide evidence that some learners developed a stronger ability to explain the mathematical relationships underlying total surface area. Learners were observed explaining formulas in their own words and distinguishing between curved and flat surfaces. The post-test results also showed particularly strong performance on Questions 3 and 4, although Questions 1 and 5 remained difficult.

These findings can be interpreted through Kolb's AC stage. At this stage, learners move beyond immediate experience and construct a more general mathematical explanation. In the present study, this involved moving from "this is the curved surface of the cylinder" toward understanding why that surface contributes a particular component to the total surface-area formula.

This interpretation also connects with Qetrani and Achtaich's (2022) distinction between procedural and conceptual knowledge. A learner can apply a formula without necessarily understanding the relationships represented by its components. The present findings suggest that the intervention created opportunities to strengthen the relationship between procedural calculation and conceptual meaning, although the remaining difficulties indicate that conceptualization was not complete for all learners.

This qualification is important. The findings do not support the claim that real-world application eliminated misconceptions. Instead, they suggest that the intervention created conditions that enabled some learners to develop more meaningful representations of the concept. The continuing difficulty with questions requiring integration of several surface components demonstrates that experiential learning remains an iterative process.

## Active experimentation and application beyond the classroom

The final stage of Kolb's cycle, AE, was reflected in learners' application of the surface-area concept to practical situations. Learners reported possible applications involving painting tanks, covering pipes, fencing, and estimating materials. L8, for example, explained that the knowledge could be used to calculate the amount of paint needed for a round water tank.

This finding is consistent with research showing that realistic mathematics can help learners connect formal mathematical knowledge with practical situations. Fraihat et al. (2022) reported positive effects of situated learning on mathematical reasoning, while Tessema et al. (2024) found positive contributions of hands-on realistic learning to conceptual understanding and problem-solving in solid geometry.

The present study extends this literature by showing how application was incorporated into the learning cycle itself. Learners did not first learn the formula and then receive a real-world problem as an afterthought. Rather, practical contexts, physical models, reflection, formalization, and application were connected throughout the intervention. Active experimentation therefore represented the point at which learners tested whether the mathematical relationships developed during earlier stages could be used to solve practical problems.

## Why the approach may have been meaningful in the Eastern Cape context?

The Eastern Cape context adds an important dimension to interpreting these findings. The value of the intervention was not simply that it used "real-world" objects; it was that learners could recognize those objects and relate mathematical calculations to situations outside the formal mathematics classroom. Learners referred to tanks, drums, pipes, fencing, and materials in describing potential applications.

This finding is consistent with research emphasizing that realistic contexts are most useful when they are meaningful to learners and genuinely connected to mathematical content (González, 2017). It also responds to evidence from South African geometry education indicating that contextualization can be limited in learning materials. Mthethwa et al. (2024), for example, found that geometry tasks in the South African textbooks they examined were predominantly intra-mathematical, with contextualization largely absent.

The present findings therefore suggest a possible contextual contribution: real-world applications can provide learners with a reason for engaging with an abstract geometric concept while simultaneously giving them a concrete basis for constructing mathematical meaning. This does not mean that contextualized learning will necessarily work in the same way in every Eastern Cape school. Rather, the finding demonstrates the potential relevance of carefully selected familiar contexts within the classroom investigated.

## Engagement as part of the learning mechanism

Learners also reported that the intervention was more interesting and engaging than routine mathematics lessons. L9 explained that model construction and group work made the lesson more exciting because learners were "doing the work ourselves." Classroom observations similarly recorded questioning, discussion, peer interaction, and increasing initiative.

These findings support previous research linking realistic contexts with learner engagement, but they also provide a deeper interpretation. Engagement may have functioned as a mechanism supporting the experiential learning cycle. When learners were interested in the context, they participated more actively; active participation created opportunities for discussion and reflection; discussion exposed misconceptions and alternative approaches; and these interactions created opportunities for conceptual development.

Thus, learner-reported interest and engagement should not be treated as independent evidence of improved achievement. In this study, they are interpreted as experiences that may have created opportunities for learners to participate in the concrete, reflective, conceptual, and experimental processes described by Kolb.

## Conclusion

This study found that teaching the total surface area of a cylinder through real-world applications was associated with improved Grade 10 learner performance and positive learning experiences. Mean performance increased from pre-test to post-test, with a statistically significant difference, $t(38) = 6.30, p < .001$, and a large effect size (Cohen's $d = 1.01$). Qualitative findings further indicated that learners valued familiar cylindrical objects, visual representations, model construction, collaborative activities, and practical problem-solving, suggesting that these experiences helped connect formal surface-area calculations with meaningful situations.

Viewed through Kolb's ELT, the findings suggest that the intervention created opportunities for learners to progress from concrete experience and reflection toward mathematical conceptualization and application. Nevertheless, some difficulties remained in integrating the different components of cylinder surface area, indicating that experiential activities may support conceptual development without necessarily resolving all learning difficulties.

Finally, the study provides context-specific evidence that structured real-world and experiential activities can support the teaching and learning of the total surface area of a cylinder in a Grade 10 Eastern Cape classroom. However, the single-school sample and absence of a control group limit the extent to which the findings can be attributed specifically to the intervention or generalized to other learners and contexts. Future research should therefore examine similar interventions using comparative designs and more diverse learner populations to determine their broader applicability and sustained effects.

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## Conflicts of Interest

The authors declare that no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely avoided by the authors.

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## APPENDIX A: SEMI-STRUCTURED INTERVIEW

1 How do you feel about using real-world applications to learn about the total surface area of a cylinder?

2 Do you think learning with real-world applications made the lesson more interesting or engaging compared to lessons without them?

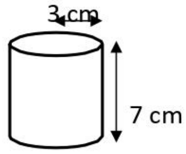
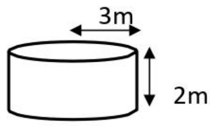
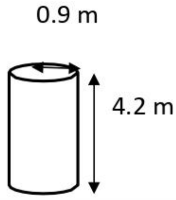
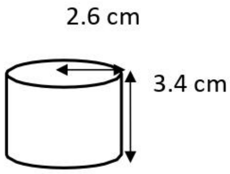
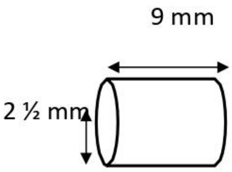
3 In what ways do you think learning about the total surface area of a cylinder through real-world applications could help you outside the classroom?

## APPENDIX B: PRE-TEST AND POST-TEST

Date

# PRE-TEST :MEASUREMENT

*Use the radius measurement to find the total surface area of these cylinders. Give your answers to 2 decimal places.*

| CYLINDER | WORKING OUT |
|---|---|
| 1)   | |
| 2)   | |
| 3)   | |
| 4)   | |
| 5)   | |