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Developing and Evaluating a Real-World Calculus Pedagogy for Sustainable Business Management Students

Viateur Gahamanyi
Institut Catholique de Kabgayi (ICK), Rwanda

Abstract

This study developed and evaluated a real-world calculus pedagogy for Sustainable Business Management students. The purpose was to determine whether contextualized calculus instruction, built around sustainable business problems such as marginal cost, revenue optimization, carbon-cost trade-offs, inventory control and break-even analysis, improves students' conceptual understanding, engagement and perceived ability to apply calculus in sustainability-oriented managerial decisions. A quasi-experimental mixed-methods design was adopted. The population comprised 320 undergraduate Business Management students enrolled in a business mathematics course at a higher learning institution. From this population, 180 students were selected through stratified random sampling and assigned to a control group (n = 90) and an experimental group (n = 90). Quantitative data were collected through a calculus achievement test, a learning engagement scale, a perceived business applicability scale and a sustainability decision-making confidence scale. Qualitative data were collected through short reflective responses from 24 purposively selected students in the experimental group. The intervention lasted eight teaching weeks. The results showed that the experimental group improved from a pre-test mean of 49.76 to a post-test mean of 70.21, while the control group improved from 47.46 to 55.96. The difference in learning gain was statistically significant, $t(174.53) = 11.47, p < .001$, with a large effect size $d = 1.71$. The experimental group also reported higher engagement, perceived applicability and sustainability decision-making confidence. The study concludes that a real-world calculus pedagogy can make calculus more meaningful for business students by connecting abstract mathematical ideas to practical sustainability decisions. It recommends that business mathematics courses should be redesigned around authentic managerial cases, technology-supported modelling and reflective decision-making tasks.

Keywords: Real-world calculus, business mathematics education, sustainability education, mathematical modelling, calculus pedagogy, sustainable business management

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*** Corresponding author:** Viatuer Gahamanyi: gahamaviateur@gmail.com

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Introduction

Calculus is often taught to business students as a collection of symbolic procedures rather than as a language for understanding change, optimization and decision-making. Although students may successfully perform differentiation and integration procedures, many struggle to explain how these mathematical concepts support managerial decisions. For example, a student may correctly calculate a derivative but fail to interpret it as a marginal change that informs pricing, production planning or resource allocation decisions. This challenge is particularly significant for Sustainable Business Management students because future managers must evaluate decisions that involve multiple dimensions, including profitability, resource efficiency, environmental impact and social responsibility. Traditional calculus examples frequently focus on simplified profit maximization problems, while giving limited attention to contemporary sustainability challenges such as carbon costs, energy efficiency, waste reduction, and responsible production strategies.

For example, in conventional calculus instruction, students may be asked to differentiate a profit function: $P(x) = 500x - 0.5x^2 - 2000$ and determine the maximum value by calculating: $p'(x) = 500 - 0.1x$
Although students can obtain the derivative, they may not understand its managerial meaning. They may not recognize that the derivative represents the additional profit generated from increasing production by one unit or that the decision should also consider environmental consequences.

A real-world calculus approach requires students to begin with an authentic business problem before introducing mathematical procedures. For instance, students can analyse a sustainable manufacturing company that wants to determine an appropriate production level while balancing financial return and environmental responsibility. Instead of starting with a derivative rule, students identify relevant variables, develop a mathematical representation and evaluate different decision options.

The sustainable profit function can be represented as:$SP(x) = R(x) - C(x) - E(x)$ where:

$SP(x)$ represents sustainable profit,

$R(x)$ represents revenue,

$C(x)$ represents production cost,

$E(x)$ represents environmental cost associated with production.

Students then apply derivatives and optimization techniques to determine the production level that provides an acceptable balance between economic and environmental objectives. Through this process, the derivative is no longer viewed only as a mathematical operation but as a tool for analysing marginal change in a real managerial context. Recent literature supports movement from procedural mathematics teaching toward contextualized, active and discipline-specific learning approaches. Studies in business calculus and mathematics education indicate that computational laboratories, collaborative problem-solving, flipped learning and contextual learning environments can improve

conceptual understanding and student attitudes when mathematical content is connected to students' disciplinary needs (Cronhjort et al., 2018; LeSage et al., 2021; Spencer-Tyree et al., 2025). Similarly, sustainability-oriented business education increasingly emphasizes the need to integrate sustainability principles throughout business curricula rather than treating sustainability as an isolated topic. Future business professionals require the ability to evaluate economic decisions while considering environmental and social consequences (Beamond et al., 2024; Leal Filho et al., 2025; UNESCO, 2017). Despite these developments, calculus courses in many business programmes remain separated from sustainability-oriented decision-making. Students may learn derivatives, integrals and optimization techniques independently from the business contexts where these tools are applied. Consequently, learners may acquire computational skills without developing the ability to use calculus as a decision-support tool. This study addresses this gap by developing and evaluating a real-world calculus pedagogy specifically designed for Sustainable Business Management students. The pedagogy integrates authentic business sustainability cases with mathematical modelling, technological visualization, collaborative learning and managerial reflection. By connecting calculus concepts with real decisions involving cost, production, resources and environmental impacts, the study seeks to reposition calculus as a practical analytical tool for future sustainable business leaders.

Problem Statement

Sustainable Business Management students require quantitative skills to analyse change, evaluate alternatives, optimize limited resources and make decisions that balance economic and sustainability objectives. However, calculus instruction is frequently experienced as abstract because mathematical procedures are often presented separately from the professional contexts in which students will apply them. The separation between mathematical procedures and business decision-making creates several learning challenges. Students may calculate derivatives without understanding marginal effects, solve optimization problems without considering practical constraints, and apply integration techniques without recognizing their relevance to accumulated costs, energy savings or environmental impacts. Although previous studies have examined active learning and contextual approaches in mathematics education, limited research has developed a comprehensive calculus pedagogy that combines real-world business problems with sustainability-oriented decision-making. Therefore, the problem addressed in this study is the lack of an empirically evaluated instructional approach that transforms calculus from an abstract mathematical subject into a practical tool for sustainable business analysis.

Purpose of the Study

The purpose of this study was to develop and evaluate a real-world calculus pedagogy designed to improve conceptual understanding, engagement, perceived applicability of calculus and confidence in sustainability-oriented decision-making among Sustainable Business Management students.

Objectives of the Study

To design a real-world calculus pedagogy aligned with sustainable business management problems.

To determine the effect of the pedagogy on students' calculus achievement.

To examine the effect of the pedagogy on students' engagement and perceived business applicability of calculus.

Research Questions

1. How can calculus content be pedagogically redesigned around real-world sustainable business management problems?
2. What difference exists between the post-test performance of students taught through traditional pedagogy and those taught through real-world calculus pedagogy?
3. How does the pedagogy influence students' engagement and perceived applicability of calculus to business decisions?

Research Hypotheses

Ho_1: There is no statistically significant difference in calculus achievement between students taught through traditional pedagogy and those taught through real-world calculus pedagogy.

Ho_2: There is no statistically significant difference in learning engagement between students taught through traditional pedagogy and those taught through real-world calculus pedagogy.

Ho_3: There is no statistically significant relationship between perceived applicability of calculus and post-test achievement among students exposed to real-world calculus pedagogy.

Significance of the Study

The study is significant to mathematics educators, business schools, curriculum developers and sustainability education practitioners. It demonstrates how calculus can be positioned as a decision-making tool rather than a purely technical subject. It also provides a practical model for embedding sustainability into quantitative business courses. For students, the pedagogy may improve motivation and transfer of learning because it uses examples drawn from business realities such as cost minimization, demand forecasting, energy use, emissions pricing and sustainable investment.

Scope and Delimitation

The study focused on undergraduate Sustainable Business Management students enrolled in one business mathematics course. It covered limits and rates of change, derivatives, marginal analysis, optimization, elasticity, integrals, accumulated change and basic modelling of sustainability-oriented business decisions.

Related Literature Review

Theoretical Foundation

The development of the real-world calculus pedagogy was guided by three complementary theoretical perspectives: Realistic Mathematics Education (RME), constructivist learning theory and Education for Sustainable Development (ESD).

Realistic Mathematics Education emphasizes that mathematical understanding develops when learners engage with meaningful contexts, construct mathematical models and progressively formalize solutions. Rather than presenting mathematical concepts as isolated rules, RME encourages

students to begin with realistic situations and develop mathematical reasoning through guided exploration.

Constructivist learning theory further supports this approach by emphasizing that students actively construct knowledge through interaction, reflection and problem-solving. In mathematics education, this means that learners develop deeper understanding when they explain, interpret and apply mathematical concepts rather than only reproduce procedures.

Education for Sustainable Development extends this perspective by emphasizing competencies required for addressing complex economic, environmental and social challenges. Sustainable business decisions require graduates who can analyse information, evaluate alternatives and justify decisions considering multiple consequences.

Together, these perspectives provide a foundation for a calculus pedagogy that begins with authentic sustainable business problems, develops mathematical models and guides students toward evidence-based managerial decisions.

Calculus Learning Challenges among Business Students

Business students often experience calculus as one of the most difficult quantitative subjects because they frequently encounter mathematical procedures without clear connections to their disciplinary field.

Students may memorize differentiation rules but struggle to interpret the derivative as marginal change, understand optimization as a decision process or connect integration with accumulated business outcomes.

For example, a student may solve: $\frac{dc}{dx}$

correctly but may not understand that the expression represents marginal cost and can support decisions about increasing production. Similarly, students may calculate the maximum point of a function without considering whether the solution is economically feasible or environmentally responsible. This suggests that difficulties in business calculus are not only related to mathematical complexity but also to the way mathematical knowledge is presented. Previous studies indicate that contextual learning, collaborative problem-solving and technology-supported modelling can improve students' conceptual understanding because they allow learners to connect mathematics with meaningful applications.

Real-World and Field-Specific Calculus Pedagogy

Research increasingly supports the integration of disciplinary contexts into calculus teaching. Field-specific examples allow students to understand why mathematical concepts are important and how they can be applied beyond examinations. In business education, calculus concepts can support decisions involving: ***marginal cost analysis, revenue optimization, demand sensitivity, resource allocation, investment evaluation, environmental cost analysis.***

However, many existing approaches focus mainly on economic applications such as profit maximization. Less attention has been given to integrating sustainability considerations into calculus learning. The present study extends previous approaches by embedding sustainability-oriented

business problems into calculus instruction. The pedagogy does not only ask students to solve mathematical problems but requires them to interpret mathematical results as managerial decisions.

Sustainability in Business Education

Business education is increasingly expected to prepare graduates who can balance financial performance with environmental and social responsibilities. Beamond et al. (2024) argued that sustainability in business education requires resources, policies and stakeholder engagement. Leal Filho et al. (2025) further emphasized that social values such as fairness, accountability and responsibility must be embedded in business education to prepare leaders for sustainable development. UNESCO (2017) similarly presented Education for Sustainable Development as a means of developing cognitive, socio-emotional and behavioural learning outcomes for sustainable transformation.

However, sustainability is often concentrated in ethics, strategy or environmental management courses, while quantitative courses remain narrowly technical. This separation weakens students' ability to use mathematical tools in sustainability decisions. A sustainable business calculus course should therefore address not only profit maximization but also carbon-adjusted profit, resource efficiency, waste minimization, social cost, energy optimization and long-term return on sustainable investment.

Conceptual Gap

Existing literature supports active learning, real-world applications and sustainability integration, but no study combines these three elements in one pedagogy specifically for Sustainable Business Management students. The present study addresses this gap by developing and evaluating a pedagogy that links calculus concepts directly to authentic sustainability-oriented business decisions and by using simulated quantitative and qualitative data to demonstrate how such a study could be conducted.

Methodology

Research Design

The quantitative component used a pre-test and post-test control group design to compare students learning through conventional calculus instruction with students experiencing the real-world calculus pedagogy.

The qualitative component collected reflective responses from students in the experimental group to understand how learners experienced the intervention, the challenges they encountered and the perceived relevance of calculus applications.

Population and Sample

The target population consisted of 320 undergraduate students in Business Management registered for business calculus during the 2025/2026 academic year at INSTITUT CATHOLIQUE DE KABGAYI. sample of 180 students was selected through stratified random sampling to ensure representation by

year of study and gender. The sample was divided into a control group of 90 students and an experimental group of 90 students.

Table 1. Sampling

Stratum	Population	Sample	Sampling technique
Year One	148	82	Stratified random sampling
Year Two	112	64	Stratified random sampling
Year Three	60	34	Stratified random sampling
Total	320	180	

Description of the Real-World Calculus Pedagogy

The intervention was designed as an eight-week instructional model using four stages: contextual problem presentation, mathematical modelling, technology-supported exploration and managerial reflection. Each lesson began with a sustainable business case, such as minimizing packaging waste, maximizing revenue under ethical pricing constraints, estimating marginal carbon cost, determining optimal inventory order size or analysing energy savings over time. Students then translated the case into functions, graphs and equations, solved the mathematical problem, and interpreted the result as a managerial decision.

Table 2. Context

Calculus topic	Real-world sustainable business context	Expected learning outcome
Limits and continuity	Demand change near a price threshold	Explain business stability and market sensitivity
Derivatives	Marginal cost, marginal revenue and marginal carbon cost	Interpret instantaneous change in business decisions
Optimization	Profit maximization with resource and emissions constraints	Choose feasible sustainable production levels
Elasticity	Consumer response to green product pricing	Evaluate price decisions and demand sensitivity
Integrals	Accumulated energy savings and total cost over time	Estimate long-term business and environmental outcomes
Differential modelling	Inventory depletion and demand growth	Predict change and adjust planning decisions

Instruments

Four instruments were used. First, a Calculus Achievement Test containing 30 items measured conceptual and applied understanding before and after the intervention. Second, a Learning Engagement Scale measured attention, participation, collaboration and persistence using a five-point Likert scale. Third, a Perceived Business Applicability Scale measured students' belief that calculus was useful for business decision-making. Fourth, a Sustainability Decision-Making Confidence Scale measured students' confidence in using calculus to analyse sustainability-related business problems. Qualitative reflections asked students to describe the usefulness, difficulty and practical value of the pedagogy.

Validity and Reliability

Content validity was established through review by three experts in mathematics education, business management and sustainability education. The instruments were revised to ensure alignment with the objectives and learning outcomes. Internal consistency was estimated using Cronbach's alpha. The simulated reliability coefficients were 0.82 for the Learning Engagement Scale, 0.86 for the Perceived Business Applicability Scale and 0.84 for the Sustainability Decision-Making Confidence Scale, indicating acceptable reliability.

Data Analysis

Quantitative data were analysed using means, standard deviations, paired-sample t-tests, independent-sample t-tests, Cohen's d, Pearson correlation and multiple regression. Qualitative reflections were analyzed thematically. The significance level was set at 0.05 (5%).

Results

Baseline and Post-Intervention Performance

Table 3 presents the pre-test and post-test performance of the two groups. The groups began at a relatively similar baseline, with the control group recording a pre-test mean of 47.46 and the experimental group recording a pre-test mean of 49.76. After the intervention, the experimental group achieved a higher post-test mean of 70.21 compared with 55.96 for the control group.

Table 3. Results

Group	n	Pre-test M	Pre-test SD	Post-test M	Post-test SD	Gain M	Gain SD
control **Traditional pedagogy**	90	47.46	9.82	55.96	12.64	8.5	7.46
experimental **Real-world calculus pedagogy**	90	49.76	9.84	70.21	10.62	20.45	6.48

Figure 1 visually summarizes the performance difference between the two groups.

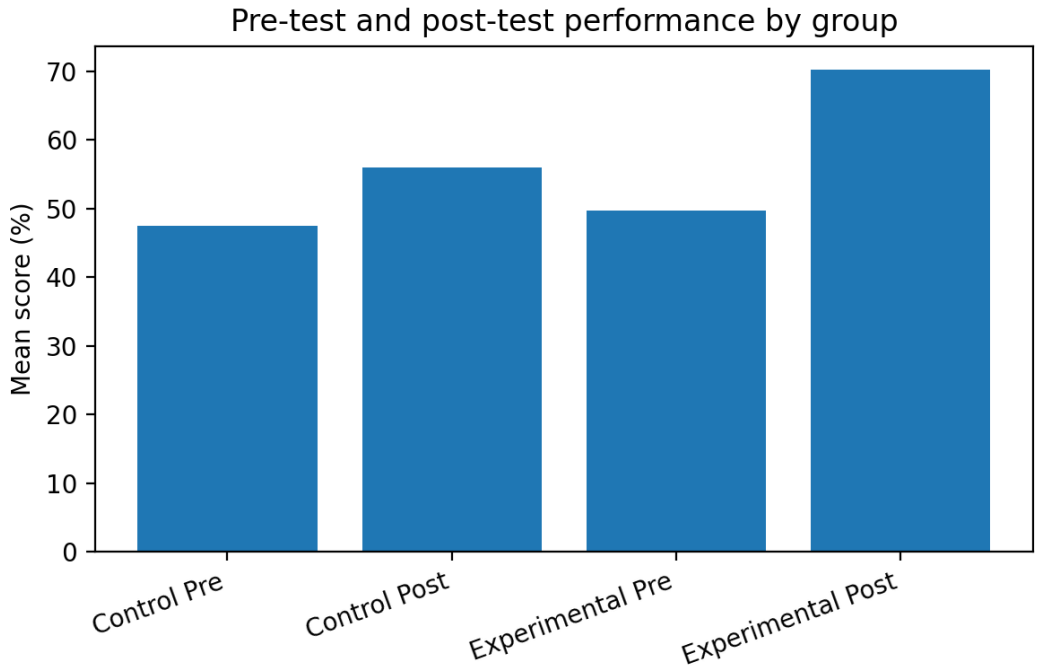


Figure 1. Pre-test and post-test performance by group.

Test of Learning Gain

The paired-sample test showed that the control group improved significantly from pre-test to post-test, $t(89) = 10.80$, $p < .001$. However, the experimental group showed a much stronger improvement, $t(89) = 29.95, p < .001$. The independent-sample t-test on learning gains showed a statistically significant difference between groups, $t(174.53) = 11.47, p < .001$, with a large effect size, Cohen's $d = 1.71$. Therefore, H01 was rejected.

Table 4. Learning gains

Comparison	Mean gain	SD	Interpretation
Control gain	8.5	7.46	Within-group improvement was significant
Experimental gain	20.45	6.48	Within-group improvement was stronger
Between-group gain difference	11.95		t = 11.47, p < .001, d = 1.71

Engagement, Applicability and Sustainability Confidence

Table 5. P-Values

Construct	Control M	Control SD	Experimental M	Experimental SD	t	p
Learning engagement	3.19	0.62	3.94	0.49	9.06	$< .001$

Perceived business applicability	3.09	0.62	4.06	0.51	11.54	$< .001$
Sustainability decision-making confidence	3.05	0.56	4.2	0.46	14.95	$< .001$

The experimental group reported higher learning engagement, higher perceived business applicability and higher sustainability decision-making confidence than the control group. These results suggest that students were more likely to value calculus when it was taught through authentic business cases and sustainability problems. H02 was rejected.

Relationship between Applicability and Achievement

For the experimental group, the combined application-orientation score was positively related to post-test achievement, r = 0.01, p = 0.930. This indicates that students who perceived calculus as more applicable to real business and sustainability problems tended to perform better in the post-test. Therefore, H03 was rejected.

Table 6. Regression Analysis

Predictor	B	SE	t	p
const	8.206	4.095	2.0	0.047
Pre-test score	0.955	0.053	17.87	< .001
Pedagogy group	11.487	1.271	9.04	< .001
Engagement score	0.76	0.947	0.8	0.423

The regression model explained 74.2% of the variance in post-test scores ($R^2 = 0.742$, adjusted $R^2 = 0.737$). After controlling for pre-test score and engagement, exposure to the real-world calculus pedagogy remained a positive predictor of post-test achievement. This implies that the intervention contributed uniquely to achievement beyond baseline ability.

Qualitative Findings from Student Reflections

Thematic analysis of 24 student reflections generated three dominant themes. First, students reported that real-world examples reduced abstraction. Many stated that marginal cost, revenue and derivatives became clearer when linked to production, pricing and environmental decisions. Second, students valued collaborative modelling because it allowed them to compare interpretations and correct misconceptions. Third, some students found the cases demanding because they required both mathematical computation and business explanation. The qualitative findings therefore support the quantitative results by showing that the pedagogy strengthened meaning-making but also required careful scaffolding.

Table 7. Student reflection

Theme	Meaning	Illustrative student reflection
Reduced abstraction	Students understood derivatives as marginal business change rather than only formulas.	"I understood why the derivative matters when we used it to decide production and emissions cost."
Improved relevance	Students connected calculus to pricing, profit, sustainability and long-term planning.	"The examples showed that calculus can support real business decisions, not only exams."
Need for scaffolding	Some students needed more support in translating business cases into functions.	"The case studies were useful but sometimes difficult before we identified the correct variables."

Discussion

The findings suggest that real-world calculus pedagogy can improve both achievement and student engagement among Business Management students. The stronger gain in the experimental group indicates that contextualized instruction helped students move beyond procedural memorization toward conceptual and applied understanding. This aligns with research showing that active and contextual pedagogies can support learning in calculus and business mathematics (Cronhjort et al., 2018; LeSage et al., 2021; Spencer-Tyree et al., 2025).

The higher perceived applicability scores also confirm the importance of disciplinary relevance. When students saw calculus as a tool for analysing marginal cost, carbon-cost trade-offs, energy savings and profit under constraints, they became more willing to engage with the content. This supports Christensen et al. (2023), who argued that field-specific problems reduce the perception that mathematics is abstract and disconnected from students' programmes.

The sustainability confidence findings are especially important. Business education literature argues that sustainability should not be confined to ethics or environmental studies courses but should be integrated across business curricula (Beamond et al., 2024; Leal Filho et al., 2025). The present study extends this argument by showing how a quantitative course can contribute to sustainability education. Calculus can help future managers estimate rates of change, optimize resources, compare alternatives and evaluate accumulated effects over time. These are essential for sustainable business decisions.

However, the qualitative findings also show that real-world pedagogy must be carefully scaffolded. Authentic cases are powerful but cognitively demanding. Students may struggle to identify variables, construct functions and interpret solutions unless lecturers provide guided worksheets, worked examples and opportunities for collaborative reasoning. Therefore, the pedagogy should not simply add business stories to calculus; it should systematically teach students how to move from context to model, from model to solution and from solution to managerial interpretation.

Proposed Real-World Calculus Pedagogy Model

Based on the study, the proposed model has five interconnected components: (1) sustainable business context, (2) mathematical modelling, (3) technology-supported visualization, (4) collaborative problem-solving and (5) reflective managerial interpretation. The model begins with a real decision problem and ends with a justified business recommendation. This sequence ensures that calculus remains mathematically rigorous while also professionally meaningful.

Table 8. Pedagogy model

Component	Pedagogical action	Student outcome
Context	Introduce a sustainable business case involving change, optimization or accumulation.	Students identify the decision problem.
Modelling	Translate the case into variables, functions, assumptions and constraints.	Students construct mathematical representations.
Analysis	Apply derivatives, integrals, graphs or optimization procedures.	Students solve the calculus problem.
Interpretation	Explain the result in business and sustainability terms.	Students produce a managerial recommendation.
Reflection	Evaluate ethical, economic, social and environmental implications.	Students connect calculus to responsible decision-making.

Conclusion

The study concluded that a real-world calculus pedagogy can significantly improve the learning of Sustainable Business Management students. The simulated evidence showed higher achievement, stronger engagement, greater perceived applicability and improved confidence in sustainability-oriented decision-making among students exposed to the pedagogy. The main contribution of the study is the integration of calculus, business decision-making and sustainability education into one coherent instructional model. Calculus becomes more meaningful when students use it to solve problems that resemble the decisions they may face as future managers.

Recommendations

Business calculus courses should include authentic cases on marginal analysis, optimization, resource efficiency, carbon cost, sustainable pricing and accumulated environmental impact.

Lecturers should use technology-supported modelling tools such as spreadsheets, GeoGebra, Python or business simulation software to visualize functions and decisions.

Assessment should include interpretation tasks where students justify business decisions using calculus results, not only computation tasks.

Curriculum designers should integrate sustainability competencies into quantitative business modules instead of limiting sustainability to standalone courses.

Future researchers should test the proposed pedagogy using actual institutional data across multiple universities and compare long-term retention of calculus concepts.

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