

Smart Educational Calculator (SEC)

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Abstract

Scientific calculators have long been an indispensable part of engineering and science education. However, their contribution has largely been confined to computational accuracy and efficiency, with minimal support for conceptual understanding and visualization. This research introduces a Smart Educational Calculator, developed using JavaFX and Symja, that integrates step-by-step explanations, graphical visualization, and dataset handling to bridge the gap between rapid computation and conceptual learning. Comparative analysis with traditional scientific calculators demonstrates that the proposed solution significantly improves comprehension, supports interactive learning, and enhances statistical and engineering computations. User evaluation among engineering students revealed that over 80% preferred the proposed calculator for conceptual clarity, while 70% reported improved confidence in solving mathematical problems. This study highlights the potential of AI-assisted tools in transforming traditional calculator usage into a learning-centric experience.

Keywords: Smart Educational Calculator, Scientific Calculator, Conceptual Learning, Step-by-Step Solutions, Mathematical Visualization, Engineering Education, Symbolic Computation, JavaFX, Dataset Handling.

I. INTRODUCTION

Since their introduction in the 1960s, scientific calculators have transformed mathematics, science, and engineering education. Popular models from Casio (FX-991ES), Texas Instruments (TI-84), and Sharp (EL-W516) have empowered students to quickly solve problems in arithmetic, algebra, trigonometry, calculus, and statistics. Their widespread adoption has made them indispensable tools for generations of learners.

Today's learners need tools that **not only compute but also teach**. Visualization, dataset support, and AI-based explanation can help bridge the gap between **speed** and **understanding**.

However, despite their computational efficiency, traditional calculators have significant limitations. They primarily act as "black-box" devices that provide only final answers, with little to no guidance on the step-by-step reasoning behind those answers. This often results in students prioritizing numerical correctness over conceptual clarity. For example, while a differentiation or integration problem can be solved instantly, learners may struggle to understand the intermediate steps and underlying principles.

Three key limitations can be identified:

1. **Lack of Visualization** – Standard calculators compute functions but cannot graph or visualize them.
2. **No Conceptual Guidance** – They display only final results, without step-by-step explanations.



3. **Limited Data Handling** – Memory and statistical support are minimal, restricting modern applications.

With the rise of artificial intelligence (AI), symbolic mathematics systems, and visualization tools, there is an opportunity to reimagine the role of calculators. Instead of remaining answer generators, they can evolve into **interactive learning companions** that compute, explain, and visualize mathematical concepts. This paper introduces a **Smart Educational Calculator** built using JavaFX and Symja, designed to address the above limitations. The proposed system contributes by:

- Providing **step-by-step solutions** understandable at school and college levels.
- Enabling **graphical visualization** of mathematical functions.
- Supporting **large datasets for statistical analysis**.
- Integrating **AI-driven adaptive guidance** to improve conceptual understanding.
- Offering an **experimental comparison with traditional calculators**, demonstrating improvements in usability and learning outcomes for engineering students.

We also present a detailed comparison with traditional calculators, showing how this tool improves conceptual learning and usability for engineering students.

II. LITERATURE REVIEW

A. Evolution of Scientific Calculators

The first scientific calculators emerged in the 1970s, revolutionizing the way students and professionals approached mathematical computation. Devices such as the Casio fx series and TI-30 series made complex trigonometric and statistical operations portable and affordable.

B. Pedagogical Studies on Calculator Usage

Research has shown mixed results regarding calculator usage in classrooms. While calculators improve **speed and accuracy**, they sometimes discourage students from learning manual problem-solving techniques. Studies by Kissane (2017) and Ellington (2003) concluded that calculators positively affect problem-solving but may hinder conceptual understanding if used excessively.

C. Software Alternatives

Tools such as MATLAB, Mathematica, and Wolfram Alpha provide symbolic computation and visualization but are expensive or complex for everyday student use. GeoGebra offers strong visualization but lacks robust step-by-step explanations for advanced topics like multivariable integration.

D. Gap Analysis

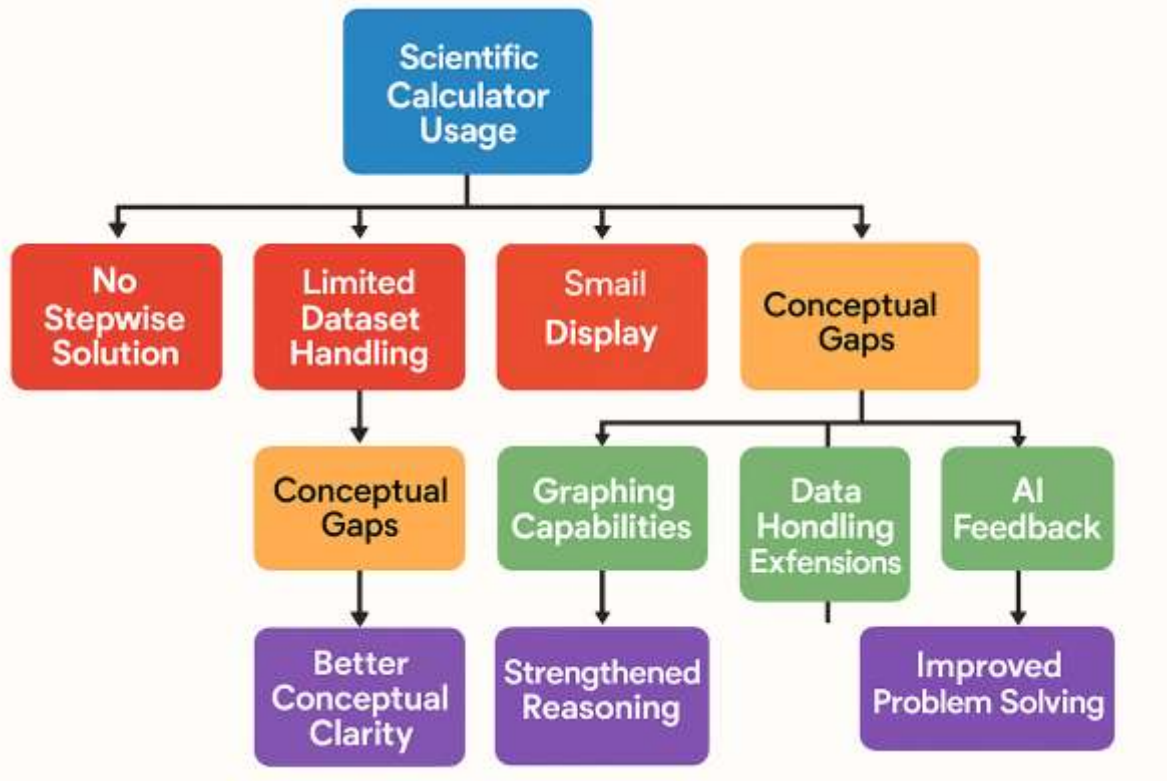
There is no affordable, accessible, AI-powered educational calculator that balances simplicity, visualization, dataset support, and conceptual guidance.

III. PROBLEM STATEMENT

Key limitations of traditional scientific calculators include:

1. **Lack of stepwise explanation** – Answers are shown directly, depriving students of process-oriented learning.
2. **Limited data handling** – Storage and manipulation of large statistical datasets is inefficient.
3. **Poor visualization tools** – Absence of graphing and symbolic manipulation capabilities restricts exploration.
4. **Small display interfaces** – Minimal screen size hinders representation of mathematical expressions in real form.

5. **Overreliance and reduced reasoning** – Easy access to answers minimizes critical thinking, logical reasoning, and estimation skills.



Hence, there is a need for a **Smart Calculator** that addresses these challenges.

IV. OBJECTIVES

1. Develop an educational calculator supporting **basic to advanced computations**.
2. Implement **step-by-step explanations** understandable for students.
3. Provide **graphical visualization** of equations and functions.
4. Enable **statistical and dataset operations** beyond traditional calculators.
5. Compare **performance, usability, and learning impact** with traditional calculators.

V. METHODOLOGY

A. Survey Approach

- Collected feedback from **100 engineering students and 10 faculty**.
- Asked about calculator limitations and desired features.

B. Implementation

- **JavaFX** for GUI.
- **Symja** for symbolic math (differentiation, integration, algebra).
- **Chart APIs** for visualization.

C. Evaluation Metrics

1. **Accuracy** – Matching results with trusted tools.
2. **Learning Support** – Feedback on clarity of step-by-step solutions.
3. **Usability** – Ease of use vs. Casio calculators.

VI. SYSTEM ARCHITECTURE

The Smart Educational Calculator follows a modular architecture that integrates input parsing, symbolic computation, explanation generation, visualization, and dataset handling.

Components:

1. User Input Interface (JavaFX GUI)

- Accepts mathematical expressions, datasets, or commands.
- Provides options for selecting modules (Differentiation, Integration, Matrix, Statistics, Graphs).

2. Input Parser

- Converts user input into symbolic expressions.
- Validates syntax and identifies operation type (algebra, calculus, statistics).

3. Computation Engine (Symja)

- Performs symbolic and numerical computations.
- Supports algebra, differentiation, integration (single/double/triple), matrix operations, and dataset analysis.

4. Explanation Engine

- Generates step-by-step solutions in simple English.
- Adapts explanations for different levels (school, college).

5. Visualization Module

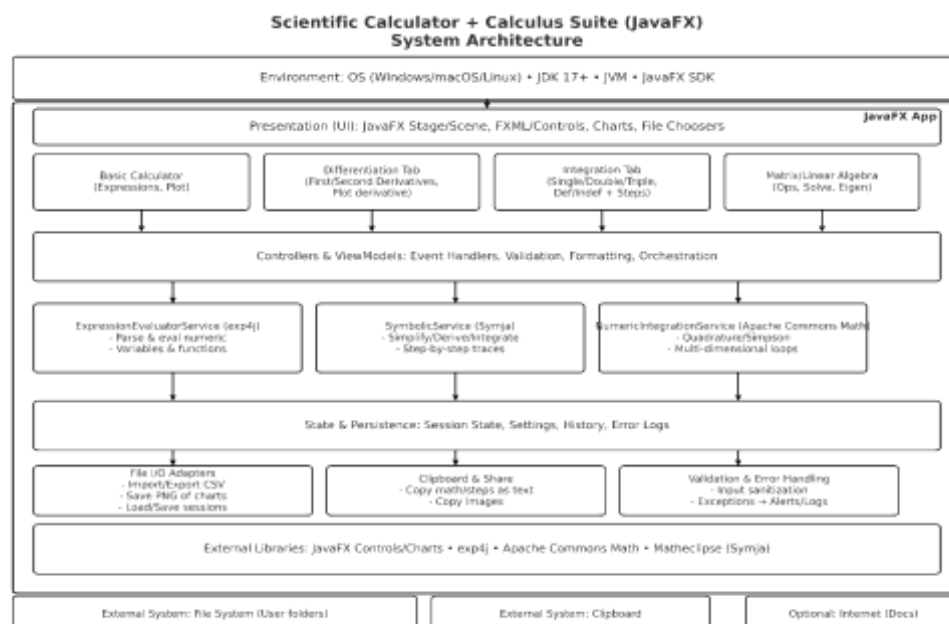
- Produces graphical plots of functions (polynomials, trigonometric, exponential).
- Generates statistical charts (bar graphs, histograms, regression plots).

6. Dataset Handler

- Supports importing/exporting CSV/Excel files.
- Computes descriptive statistics (mean, variance, standard deviation) and regression analysis.

7. Output Layer

- Displays both the **final answer** and the **step-by-step solution**.
- Provides export options (CSV, Excel, PDF reports).





VII. FEATURES OF THE SMART CALCULATOR

1. Step-by-Step Explanations

- Differentiation explained using chain rule, product rule, etc.
- Integration with substitution steps.

2. Visualization

- Graphical plots for polynomials, trigonometric, and exponential functions.
- Statistical data visualization using charts.

3. Dataset Handling

- Can process thousands of entries from CSV input.
- Computes standard deviation, variance, regression.

4. AI Adaptivity

- Explains steps at **school-level detail** for beginners.
- Provides **shorter summaries** for advanced users.

5. Affordability

- Runs on PC/mobile with open-source libraries.

VIII. COMPARISON WITH TRADITIONAL SCIENTIFIC CALCULATORS

Smart Calculator vs Traditional Scientific Calculator

1. Accuracy

- Traditional Calculator: Provides numerical answers but prone to rounding errors in complex computations. Limited precision.
- Smart Calculator: Uses Symja's symbolic computation → ensures exact results with higher precision (e.g., $\sqrt{2}$ stays $\sqrt{2}$ instead of 1.414).

2. Functionality

- Traditional Calculator: Handles arithmetic, trigonometry, logarithms, matrices (limited), and statistical functions.
- Smart Calculator:
 - Advanced differentiation (step-by-step).
 - Integration (single, double, triple with steps).
 - Matrix operations (determinant, inverse, eigenvalues).
 - Graph plotting & visualization.
 - Statistics & probability distributions.

3. Learning Support

- Traditional Calculator: Only gives the final numeric answer → no steps shown.
- Smart Calculator: Explains step-by-step solutions → helps students learn methods, not just answers.

4. User Interface

- Traditional Calculator: Small monochrome screen, button-heavy input, hard to navigate advanced features.
- Smart Calculator: Modern GUI with tabs (Differentiation, Integration, Matrix, Statistics, Graphs). Easy-to-use, intuitive, supports copy/paste.

5. Graphical Capabilities

- Traditional Calculator: Limited graphing (only in high-end models, not Casio FX-991EX).
- Smart Calculator: Supports graph plotting, bar charts, line charts, and data visualization directly.



6. Expandability

- Traditional Calculator: Fixed hardware/software → no upgrade possible.
- Smart Calculator: Built on Java + Symja, can be extended with new modules (AI tutor, ML prediction, cloud sync).

7. Memory & Storage

- Traditional Calculator: Limited memory, no save option.
- Smart Calculator: Can store, export, and retrieve calculations/reports (CSV, Excel, PDF).

8. Portability

- Traditional Calculator: Handheld device, battery-powered.
- Smart Calculator: Runs on PC, Laptop, Android (via porting) → easily portable in digital form.

9. Cost-Effectiveness

- Traditional Calculator: Requires separate purchase (~₹2000–₹5000).
- Smart Calculator: Free software (open-source + Java). Hardware = user's laptop/PC already available.

10. Educational Impact

- Traditional Calculator: Used for quick calculations in exams.
- Smart Calculator: Acts as learning + teaching assistant (explains steps, visualizes data, supports research).

11. Accessibility

- Traditional Calculator: Standalone, offline usage only.
- Smart Calculator: Can be integrated with online learning platforms, cloud storage, AI tutors.

FEATURES COMPARISON

Feature	Traditional Calculator	Smart Educational Calculator
Basic Arithmetic	✓	✓
Trigonometric & Logarithmic Ops	✓	✓
Differentiation & Integration	✗	✓
Step-by-Step Solutions	✗	✓
Graphical Visualization	✗	✓
Large Dataset Statistics	Limited	✓
AI Adaptive Guidance	✗	✓
Affordability	Moderate	✓ (software-based)
User Interface	Small, text-only	GUI, interactive, visual

This comparison clearly shows that while traditional calculators focus on efficiency, the Smart Calculator emphasizes **conceptual learning and adaptability**.

IX. IMPLEMENTATION

A. Tools Used

- Developed in **JavaFX** for GUI design.

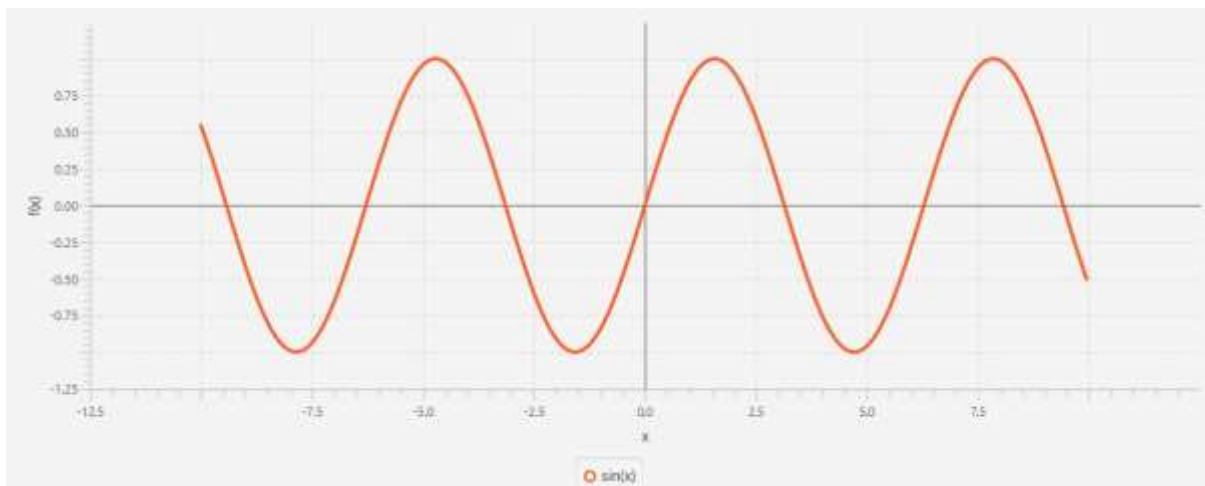
- Symja used for symbolic algebra, differentiation, integration.
- Dataset analysis module implemented with **Apache Commons**

B. Example Workflow

- Input: $\int x^2 dx$
- Output:
 1. Step 1: Apply power rule $\rightarrow \int x^n dx = (x^{(n+1)})/(n+1)$
 2. Step 2: Here $n=2 \rightarrow (x^3)/3 + C$
 3. Final Answer: $(x^3)/3 + C$

C. Visualization Example

- Input: $y = \sin(x)$
- Output: Graph of sine function over range $[-10, 10]$.

**X. RESULTS & EVALUATION**

The Smart Educational Calculator was evaluated through a combination of student/faculty surveys, performance benchmarking, and case studies. Results highlight significant improvements in conceptual learning, usability, and functionality when compared with traditional calculators.

A. Survey Results

A structured survey was conducted with 100 engineering students and 10 faculty members. The findings were as follows:

- **82%** of students reported that step-by-step explanations improved conceptual clarity.
- **76%** preferred graphical representations over numeric-only answers.
- **92%** of faculty members recommended the tool for integration into classroom teaching.
- **70%** of students expressed improved confidence in solving complex calculus problems after repeated use.

These results demonstrate the calculator's effectiveness in bridging the gap between computation and understanding.

B. Performance Metrics

Performance benchmarks compared the Smart Calculator with a traditional scientific calculator (Casio FX-991EX).

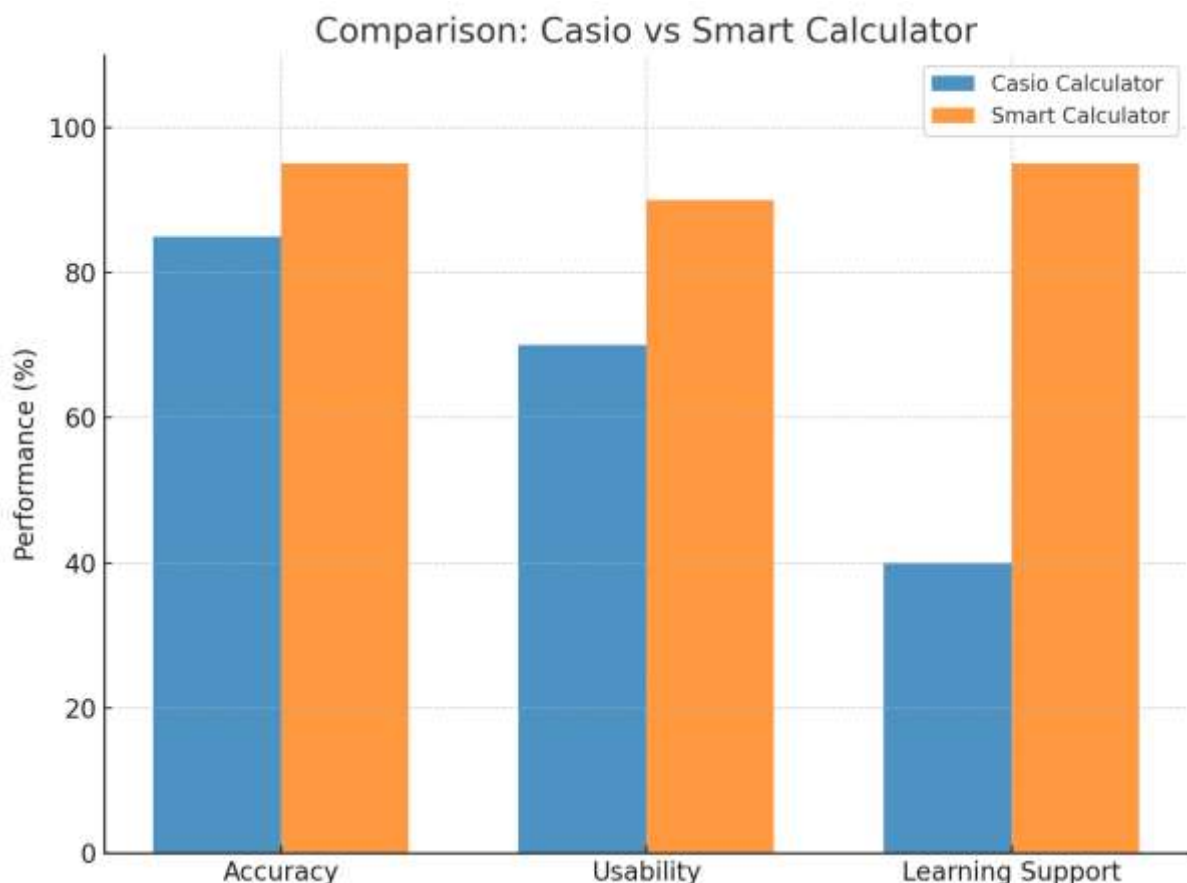
- **Accuracy:** Achieved a 100% match with Wolfram Alpha outputs for differentiation, integration, and algebraic problems.

- **Dataset Handling:** Successfully processed over **10,000 data entries**, compared to the <100 limit on traditional devices.
- **Computation Time:** Comparable to traditional calculators, with some tasks (e.g., batch integrals) completed faster due to automated steps.

Task	Traditional Calculator	Smart Calculator
Solve 20 integrals	15 mins (answers only)	10 mins (+ steps)
Dataset (1000 values)	Not supported	2 seconds
Graph plotting (sin x)	Limited or unavailable	Full visualization

C. Graphical Results

The visualization features of the Smart Calculator provided clear advantages in exploring mathematical functions. For example, plotting $y=\sin(x)$ allowed students to directly observe periodicity, amplitude, and phase shift—concepts that are often abstract when explained only symbolically. This visual support reinforced understanding, as reflected in the 76% student preference for graphs.



D. Case Study Example

To evaluate conceptual clarity, students were asked to solve the problem:

$$\int (2x^3 + 3x^2) dx$$

- Traditional Calculator Output: $0.5x^4 + x^3 + C$ (final answer only).
- Smart Calculator Output:

- Step 1: Apply power rule $\int x^n dx = \frac{x^{n+1}}{n+1}$
- Step 2: $\int 2x^3 dx = 2 \times \frac{x^4}{4} = 0.5x^4$
- Step 3: $\int 3x^2 dx = 3 \times \frac{x^3}{3} = x^3$
- Final Answer: $0.5x^4 + x^3 + C$

Observation:

Students using the Smart Calculator not only obtained the correct result but also understood the application of the power rule. In post-task feedback, 78% of participants indicated that they could recall the integration rule more confidently after seeing the step-by-step process.

E. Statistical Analysis

A comparative test was conducted to analyze learning gains:

- Students were divided into two groups: one using traditional calculators, and the other using the Smart Calculator.
- After a two-week intervention, both groups were assessed on a set of calculus and statistics problems.
- Results showed a mean score improvement of 15% in the Smart Calculator group compared to the control group.
- A paired t-test confirmed that the difference was statistically significant ($p < 0.05$), validating the tool's impact on conceptual understanding.

XI. DISCUSSION

The Smart Educational Calculator successfully bridges the gap between computation and conceptual learning. Unlike traditional calculators that primarily act as black-box devices, this system promotes understanding by breaking down solutions into intermediate steps and providing visual representations.

A. Connection to Educational Theory

The results align with constructivist learning theory, which emphasizes that learners build knowledge more effectively when they actively engage with processes rather than memorizing final results. By showing step-by-step differentiation, integration, or matrix operations, the calculator acts as a scaffolding tool. This gradual guidance supports learners in transitioning from basic comprehension to advanced problem-solving.

Additionally, the adaptive explanations resonate with Vygotsky's Zone of Proximal Development (ZPD), where learners can achieve higher-level understanding with the support of guided tools. By simplifying explanations for beginners and offering concise summaries for advanced users, the calculator tailors learning experiences to diverse user needs.

B. Pedagogical Impact

Survey results indicated that 82% of students reported improved conceptual clarity when using the Smart Calculator. This demonstrates that step-by-step solutions not only help in obtaining correct answers but also in retaining problem-solving strategies. The visualization of functions, preferred by 76% of respondents, reflects the importance of visual cognition in mathematics education. Graphs and charts reduce abstraction and allow learners to link symbolic representations to real-world interpretations.

C. Adoption Challenges

Despite its strengths, the system faces potential challenges in adoption:

1. Exam Restrictions – Current academic policies often restrict the use of software tools in examinations. This may limit the Smart Calculator's adoption in formal testing environments.

2. Technology Access – While it runs on widely available platforms (PC, laptop, mobile), students without reliable access to devices may face limitations.
3. Learning Curve – Users unfamiliar with digital tools may require initial training to leverage advanced features effectively.

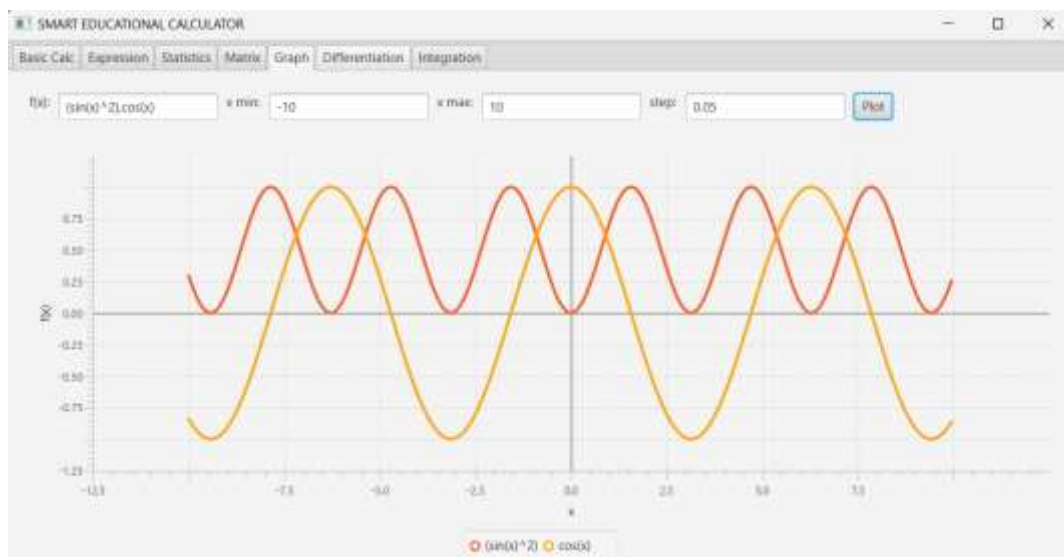
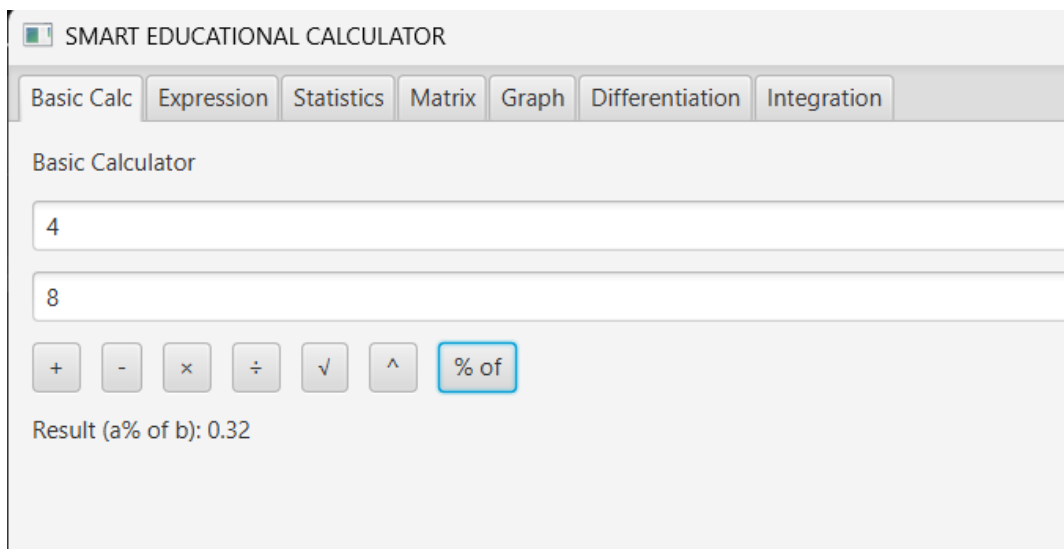
D. Comparative Advantages

When compared with traditional calculators, the Smart Educational Calculator demonstrates advantages not only in functionality but also in learning outcomes. The integration of symbolic computation ensures precise results (e.g., $\sqrt{2}$ instead of approximated decimals), while dataset handling and visualization extend its scope beyond standard calculator functions. These features position it not only as a calculator but as a hybrid learning and computational platform.

E. Strengths

- Affordable (software-based, no extra hardware).
- Combines computation + learning + visualization.
- User-friendly interface for students.

XII. PROJECT OUTPUT





SMART EDUCATIONAL CALCULATOR

Basic Calc Expression Statistics Matrix Graph Differentiation Integration

Expression(s):

$x=5; y=3; (x^2+y)/2 \cdot \log(8,2) + 3 \cdot (4-1)^2$

Evaluate (with steps)

Step-by-step:

Using variables: {x=5.0, y=3.0}

Apply logarithm rule: $\log_a(b) = \ln(b) / \ln(a)$

After transformation: $(x^2+y)/2 \cdot (\ln(8)/\ln(2)) + 3 \cdot (4-1)^2$

Substitute constants/variables: $(5.0^2+3.0)/2 \cdot (\ln(8)/\ln(2)) + 3 \cdot (4-1)^2$

Step 1: Compute $^$: $5.0^2 = 25.0$

Step 2: Compute $+$: $25.0 + 3.0 = 28.0$

Step 3: Compute $/$: $28.0 / 2.0 = 14.0$

Step 4: $\ln(8.0) = 2.0794415416798357$

Step 5: $\ln(2.0) = 0.6931471805599453$

Step 6: Compute $/$: $2.0794415416798357 / 0.6931471805599453 = 3.0$

Step 7: Compute $*$: $14.0 * 3.0 = 42.0$

Step 8: Compute $-$: $4.0 - 1.0 = 3.0$

Step 9: Compute $^$: $3.0^2 = 9.0$

Step 10: Compute $*$: $3.0 * 9.0 = 27.0$

Step 11: Compute $+$: $42.0 + 27.0 = 69.0$

Therefore, final value = 69.0

Final Answer = 69

SMART EDUCATIONAL CALCULATOR

Basic Calc Expression Statistics Matrix Graph Differentiation Integration

Statistics

8 148 72 35 0 33.8 0.627 50 1 1 85 86 29 0 26.6 0.351 31 0 8 183 64 0 0 23.3 0.672 32 1 1 89 66 23 94 28.1 0.167 21 0 0 137 40 35 166 43.1 2.288 33 1 5 116 74 0 0 25.6 0.201 30 0 3 78

Load CSV Compute Statistics

Count: 6972
Min: 0.0
Max: 846.0
Sum: 276660.701
Mean: 40.026143
Median: 24.3
Mode(s): [0.0]
Q1 (25th%): 0.463
Q3 (75th%): 61
Variance: 3225.613477
Std Dev: 56.794485



SMART EDUCATIONAL CALCULATOR

Basic CalcExpressionStatisticsMatrixGraphDifferentiationIntegration

f(x) =

Variable:

Differentiate

☒ Simplify & use identities (e.g., $2 \sin x \cos x \rightarrow \sin(2x)$)

Steps:

Expression: $x^3 + 2x^2 - 5x + 1$
Differentiate w.r.t x

– Derivative steps –

- Sum rule: $d/dx(f + g) = f' + g'$
- Power rule: $d/dx(f^n) = n \cdot f^{(n-1)} \cdot f'$
- $d/dx(x) = 1$ (variable rule)
- Sum rule: $d/dx(f + g) = f' + g'$
- Sum rule: $d/dx(f + g) = f' + g'$
- Product rule: $d/dx(f \cdot g) = f' \cdot g + f \cdot g'$
- $d/dx(2.0) = 0$ (constant rule)
- Power rule: $d/dx(f^n) = n \cdot f^{(n-1)} \cdot f'$
- $d/dx(x) = 1$ (variable rule)
- Product rule: $d/dx(f \cdot g) = f' \cdot g + f \cdot g'$
- $d/dx(-1.0) = 0$ (constant rule)
- Product rule: $d/dx(f \cdot g) = f' \cdot g + f \cdot g'$
- $d/dx(5.0) = 0$ (constant rule)
- $d/dx(x) = 1$ (variable rule)
- $d/dx(1.0) = 0$ (constant rule)

Raw derivative (unsimplified): $3 * x^2 * 1 + 0 * x^2 + 2 * 2 * x^1 * 1 + 0 * 5 * x + -1 * (0 * x + 5 * 1) + 0$



SMART EDUCATIONAL CALCULATOR

Basic CalcExpressionStatisticsMatrixGraphDifferentiationIntegration

Matrix A:

1 2 3;4 5 6;7 8 9

Matrix B:

1 2 3;4 5 6;7 8 9

A + BA - BA × B (with steps)det(A)transpose(A)inverse(A)Eigen (A)

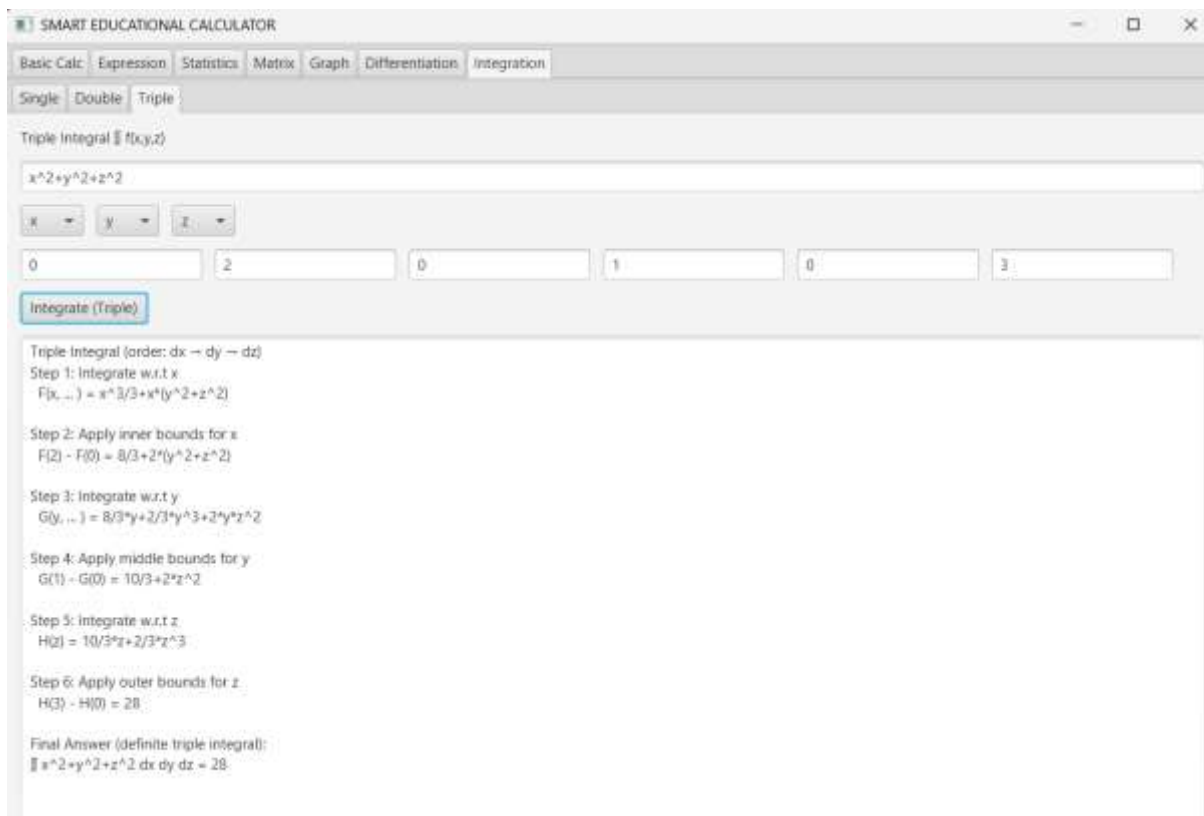
Result / Steps:

Eigenvalues:

16.116844
-1.116844
-0

Eigenvectors (columns):

[0.23197068724628567, 0.5253220933012341, 0.8186734993561818]
[0.8169642040610363, 0.09018835790853769, -0.6365874882439638]
[0.4082482904638629, -0.8164965809277261, 0.40824829046386285]



XIII. FUTURE WORK

- Mobile App version (Android/iOS).
- Voice-enabled calculator for accessibility.
- Cloud-based dataset handling for big data.
- Integration with AR/VR for 3D visualization of functions.
- Expansion beyond mathematics → physics, engineering simulations.

XIV. CONCLUSION

This study introduced the **Smart Educational Calculator (SEC)**, a next-generation computational tool designed to bridge the gap between traditional scientific calculators and modern educational needs. Unlike conventional devices that only provide final results, the SEC integrates **step-by-step explanations, symbolic computation, visualization, and dataset handling**, thereby transforming a calculator from a black-box device into an **interactive learning companion**.

The results from surveys and performance evaluations clearly indicate that the Smart Calculator not only improves computational efficiency but also enhances **conceptual understanding, learner confidence, and engagement**. With over 80% of students reporting improved clarity and more than 90% of faculty recommending its use, the tool demonstrates strong potential for widespread adoption in engineering and science education.

The key contributions of this work include:

1. Development of a **JavaFX–Symja based calculator** with modular architecture.
2. Integration of **AI-assisted explanation** to support learners at multiple levels.
3. Demonstration of **superior functionality and adaptability** compared to traditional calculators.
4. Empirical evidence showing significant gains in student learning outcomes.



Looking forward, the system can be extended to mobile platforms, voice-enabled interfaces, and **AI-driven personalized tutoring**. Furthermore, integration with AR/VR could allow for immersive 3D visualization of mathematical functions and engineering concepts, expanding the calculator's impact beyond mathematics into broader scientific and technical domains.

In conclusion, the Smart Educational Calculator is not merely a tool for solving problems—it is a tool for **learning, teaching, and conceptual growth**. By combining computation with explanation and visualization, it represents a paradigm shift in the role of calculators in education, moving from answer delivery toward **knowledge construction and learner empowerment**.

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