# Math Professor Agent

## Final Proposal

July 15, 2025

# Math Professor Agent - Final Proposal

## Overview

The Math Professor Agent is an AI-powered system designed to help users solve mathematical problems with detailed step-by-step explanations. The agent uses a combination of vector-based knowledge retrieval, web search capabilities via the Model Context Protocol (MCP), and a human feedback system to continuously improve its responses.

This agent was developed to provide accurate, clear, and educational mathematical solutions across various domains including algebra, calculus, geometry, and statistics. The system is capable of explaining complex mathematical concepts while providing detailed step-by-step solutions that help users understand the reasoning behind each mathematical operation.

## Key Features

- Mathematical Problem-Solving: Provides detailed, step-by-step solutions to a wide range of mathematical problems
- Vector Database: Stores previously solved problems for quick retrieval and improved response times
- Web Search Integration: Uses Exa API to search the internet for solutions to novel problems
- Input & Output Guardrails: Ensures only math-related questions are processed and solutions are high-quality
- Human-in-the-Loop Feedback: Allows users to provide feedback and corrections to improve future responses
- LangGraph Agent Framework: Implements a sophisticated agent workflow for complex problem-solving

## Input & Output Guardrails

We implemented robust input validation to ensure the agent only processes mathematical questions and produces high-quality solutions.

Our input guardrail uses multiple filtering strategies to ensure privacy and maintain focus on mathematical content:

- Keyword Matching: Detects math-specific terms like 'equation', 'solve', 'integral' to identify mathematical questions

- Subject Exclusion: Filters out questions about non-math subjects like history, politics, or entertainment
- Symbol Detection: Identifies mathematical symbols (+, -, *, etc.) to recognize equations even without explicit keywords
- Pattern Recognition: Detects equation patterns and numerical expressions commonly found in math problems

## Input Guardrails - Rationale

This multi-layered approach ensures that only relevant questions reach the agent while providing helpful feedback when a question is rejected. By implementing these guardrails at the input stage, we:

1. Maintain focus on mathematical content and prevent off-topic questions
2. Protect user privacy by rejecting personal or sensitive information
3. Improve efficiency by only processing questions the agent is designed to answer
4. Provide clear feedback to users when their question isn't appropriate for the system

## Output Guardrails

Our output validation ensures solutions are complete, mathematically sound, and educationally valuable:

- Completeness: Ensures the solution has both a final answer and detailed steps
- Mathematical Content: Verifies the presence of mathematical terms and symbols in the response
- Step Coherence: Confirms steps follow a logical progression and build towards the solution
- Formatting: Ensures the response is properly structured with clear delineation between steps

## Output Guardrails - Rationale

When a solution fails validation, the system falls back to a more controlled approach or generates a more constrained response. This ensures users always receive high-quality mathematical guidance and prevents misleading or incomplete solutions from being presented.

## Knowledge Base - Dataset

We used the Math-Multidomain-Enhanced dataset, which contains a comprehensive collection of

mathematical problems across various domains:

- Structure: JSON files organized by mathematical domain for efficient retrieval
- Domains: Algebra, Calculus, Geometry, Probability, Statistics, and more
- Format: Each problem includes a question, solution, and detailed steps
- Size: Over 200+ curated mathematical problems with verified solutions
- Vector Embedding: Problems are embedded using all-MiniLM-L6-v2 for semantic search

## Sample Questions from Vector DB

Try these questions which are stored in our vector database:

1. Algebra: "Solve the quadratic equation x^2 - 4x + 4 = 0 using the quadratic formula."
2. Calculus: "Find the derivative of f(x) = x^3 - 3x^2 + 2x - 1."
3. Geometry: "Calculate the volume of a sphere with radius 5 cm."

These questions demonstrate the range of mathematical topics covered in our knowledge base, from basic algebra to more advanced calculus concepts.

## Web Search Capabilities

For questions not found in our knowledge base, we implemented the Model Context Protocol (MCP) with Exa API integration for web search. This allows the agent to access current and comprehensive mathematical information from the internet.

- Session Management: Creates and maintains user sessions for consistent interactions
- Query Enhancement: Formats queries specifically for mathematical content to improve search relevance
- Fallback Mechanism: Provides reliable responses even when API fails through carefully designed fallback content
- Customized Results: Focuses on extracting step-by-step mathematical solutions from web content
- Content Filtering: Ensures that only reliable mathematical sources are used for generating solutions

## Web Search Implementation

Our MCP implementation uses the Exa API, which provides high-quality search results with full-text content extraction. This allows us to retrieve not just links but complete mathematical explanations from reliable sources.

The search process is carefully optimized for mathematical content through:
1. Query enhancement with math-specific terms
2. Prioritization of educational and mathematical websites
3. Content extraction focused on steps and formulas
4. Integration of search results into the LLM context for coherent solution generation

## Sample Web Search Questions

Try these questions that require web search:

1. "What is the formula for the volume of a truncated cone?"
2. "Explain how to use L'Hopital's rule with an example."
3. "Solve the system of equations using Cramer's rule: 3x + 2y = 7, 5x - y = 8."

These questions demonstrate the agent's ability to retrieve specialized mathematical knowledge that might not be in the core knowledge base.

## Human-in-the-Loop Mechanism

We implemented a comprehensive feedback system that allows users to rate solutions and provide corrections. This human-in-the-loop approach enables continuous improvement of the agent's responses.

- Solution Generation: The agent generates a mathematical solution based on its current knowledge
- User Feedback Collection: Users mark solutions as 'Correct' or 'Needs Improvement' and can provide specific corrections
- Solution Refinement: When corrections are provided, the agent generates an improved solution incorporating human insights
- Knowledge Integration: Feedback and corrections are stored and used to improve future responses to similar questions
- Continuous Learning: The system becomes more accurate over time as it accumulates human feedback

## Feedback System Implementation

Our feedback system is designed to be unobtrusive yet effective:

1. Each solution includes simple "Correct" and "Needs Improvement" buttons
2. When a user indicates a solution needs improvement, they can provide specific corrections
3. The system immediately generates an improved solution incorporating the user's feedback
4. Both the original question and corrected solution are stored for future reference
5. When similar questions are asked, the system consults previous feedback to provide better initial answers

This implementation creates a virtuous cycle of continuous improvement, allowing the Math Professor Agent to become more accurate and helpful over time.

## Technical Architecture

- Backend: FastAPI with LangGraph for agent orchestration and workflow management
- Frontend: React with styled-components for a responsive and intuitive user interface
- Vector Database: Qdrant for efficient similarity search of mathematical questions
- LLM: Ollama with Llama3 for generating high-quality mathematical solutions
- Web Search: Custom MCP server with Exa API integration for internet information retrieval
- Feedback Store: JSON-based storage for preserving user feedback and corrections

## Conclusion

The Math Professor Agent represents a significant advancement in AI-assisted mathematics education. By combining a comprehensive knowledge base, web search capabilities, and human-in-the-loop feedback, the system provides accurate, educational, and continuously improving mathematical guidance.

The agent's ability to explain complex mathematical concepts through step-by-step solutions makes it an invaluable tool for students, educators, and anyone seeking to understand mathematical problems more deeply.

Future enhancements will focus on expanding the knowledge base, improving the learning from feedback mechanisms, and adding support for more advanced mathematical domains and multi-modal inputs.