

Intelligent Sentiment Analysis of MOOC Reviews: A Deep Learning Approach for Educational Feedback Mining

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Abstract—The proliferation of Massive Open Online Courses (MOOCs) has generated unprecedented volumes of learner feedback, presenting both opportunities and challenges for educational institutions and Micro, Small, and Medium Enterprises (MSMEs) offering online education. This paper presents a comprehensive sentiment analysis framework for automated processing and classification of MOOC reviews to extract actionable insights at scale. We evaluated four machine learning approaches—Logistic Regression, Naive Bayes, Random Forest, and BERT—on a dataset of 140,322 Coursera course reviews. Our methodology includes a robust preprocessing pipeline incorporating text normalization, lemmatization, and TF-IDF vectorization with 5,000 features. Experimental results demonstrate that the fine-tuned BERT model achieves the highest accuracy of 87.2%, while the Random Forest classifier provides the optimal balance between performance (85.1% accuracy) and computational efficiency (100ms inference time). We further deployed the system as a production-ready REST API and interactive dashboard, enabling real-time sentiment analysis. The proposed framework addresses the critical need for automated feedback analysis in the educational technology sector, potentially saving institutions over 100 hours monthly in manual review processing while providing granular insights into learner satisfaction.

Index Terms—sentiment analysis, MOOC, educational data mining, BERT, natural language processing, text classification, machine learning, deep learning

I. INTRODUCTION

The digital transformation of education has accelerated dramatically, with MOOCs democratizing access to quality learning resources globally. Platforms such as Coursera, edX, and Udacity collectively serve millions of learners, generating massive volumes of textual feedback in the form of course reviews and comments. For MSMEs operating in the educational technology space, this user-generated content represents a valuable but underutilized resource for understanding learner satisfaction, identifying course improvement opportunities, and maintaining competitive advantage [1].

However, manual analysis of such large-scale feedback is impractical. A typical popular course may accumulate thousands of reviews, making systematic analysis prohibitively time-consuming and resource-intensive. This challenge is particularly acute for MSMEs, which often lack the infrastructure and personnel of larger competitors. Automated sentiment

analysis offers a solution by enabling scalable, real-time processing of learner feedback to extract actionable insights.

A. Motivation and Problem Statement

The primary challenges facing MSMEs in the MOOC ecosystem include:

- **Scale:** Processing 140,000+ reviews manually requires thousands of hours
- **Granularity:** Understanding not just overall sentiment but specific aspects of dissatisfaction
- **Timeliness:** Identifying emerging issues before they escalate
- **Actionability:** Converting raw sentiment into specific improvement recommendations
- **Cost:** Implementing sophisticated NLP capabilities with limited budgets

Existing sentiment analysis tools often provide binary (positive/negative) classifications with limited contextual understanding. Educational feedback, however, exhibits unique characteristics including domain-specific terminology, nuanced expressions of satisfaction, and mixed sentiments within single reviews.

B. Contributions

This paper makes the following key contributions:

- 1) **Comprehensive Framework:** We present an end-to-end sentiment analysis system specifically designed for MOOC reviews, encompassing data preprocessing, feature engineering, model training, and deployment.
- 2) **Multi-Model Evaluation:** We systematically compare four distinct approaches—classical machine learning (Logistic Regression, Naive Bayes, Random Forest) and transformer-based deep learning (BERT)—providing insights into accuracy-efficiency trade-offs.
- 3) **Production Deployment:** We demonstrate practical deployment through both REST API and interactive web dashboard, enabling real-world adoption by educational institutions and MSMEs.

- 4) **Empirical Analysis:** We provide detailed performance analysis on a large-scale real-world dataset (140,322 reviews), including confusion matrices, feature importance analysis, and computational efficiency metrics.
- 5) **Open Source Release:** All code, models, and documentation are publicly available, facilitating reproducibility and community adoption.

C. Paper Organization

The remainder of this paper is organized as follows: Section II reviews related work in sentiment analysis and educational data mining. Section III describes our methodology, including data preprocessing, feature extraction, and model architectures. Section IV presents experimental setup and results. Section V discusses findings, limitations, and implications. Section VI concludes and outlines future research directions.

II. RELATED WORK

A. Sentiment Analysis in Education

Sentiment analysis in educational contexts has gained significant attention in recent years. Wen et al. [2] applied sentiment analysis to student feedback in traditional classroom settings, demonstrating the value of automated opinion mining for course improvement. Altrabsheh et al. [3] specifically focused on MOOC reviews, using a hybrid approach combining lexicon-based and machine learning methods. Their work highlighted the unique challenges of educational sentiment analysis, including the prevalence of mixed sentiments and domain-specific vocabulary.

Recent studies have explored aspect-based sentiment analysis for education. Kastrati et al. [4] developed an aspect-based approach for MOOC reviews, identifying distinct aspects such as course content, instructor quality, and platform usability. However, their approach was limited to small datasets and did not leverage modern transformer architectures.

B. Machine Learning for Text Classification

Classical machine learning approaches have demonstrated strong performance in text classification tasks. Support Vector Machines (SVM) and Naive Bayes classifiers have been widely used due to their simplicity and effectiveness [5]. Random Forest and Gradient Boosting methods have shown superior performance in capturing complex feature interactions [6].

Feature engineering plays a critical role in classical approaches. TF-IDF (Term Frequency-Inverse Document Frequency) remains a popular choice for text vectorization, balancing term frequency with corpus-level importance [7]. N-gram features (bigrams, trigrams) capture local context and phrasal patterns [8].

C. Deep Learning for NLP

The advent of transformer architectures revolutionized NLP. Vaswani et al. [9] introduced the Transformer model with self-attention mechanisms, enabling parallel processing of sequential data. BERT (Bidirectional Encoder Representations from

Transformers) by Devlin et al. [10] demonstrated that pre-trained language models fine-tuned on specific tasks achieve state-of-the-art results across numerous benchmarks.

For sentiment analysis specifically, BERT-based models have shown substantial improvements over traditional methods. Sun et al. [11] demonstrated that fine-tuned BERT models capture nuanced sentiment expressions including sarcasm and negation. DistilBERT [12], a lighter variant, offers a favorable trade-off between performance and computational cost.

D. Educational Data Mining

Educational Data Mining (EDM) applies data science techniques to educational contexts. Romero and Ventura [13] provided a comprehensive survey of EDM applications, including student modeling, prediction of academic performance, and feedback analysis. Cobos et al. [14] specifically addressed feedback analysis in MOOCs, emphasizing the importance of actionable insights over mere classification accuracy.

E. Research Gap

While prior work has made significant contributions, several gaps remain:

- Limited comparative studies between classical ML and modern transformers in the MOOC domain
- Insufficient attention to deployment considerations and real-time inference requirements
- Lack of open-source, production-ready systems for MSME adoption
- Limited analysis of class imbalance and neutral sentiment detection challenges

Our work addresses these gaps by providing a comprehensive framework with thorough experimental evaluation and practical deployment solutions.

III. METHODOLOGY

A. Dataset Description

We utilized the Coursera Course Reviews dataset comprising 140,322 authentic user reviews collected from Coursera platform courses. The dataset includes the following attributes:

- **CourseId:** Unique identifier for each course
- **Review:** Free-text learner feedback (average 45 words)
- **Label:** Star rating (1-5 scale)

The original 5-point rating scale was mapped to three sentiment classes to balance granularity and model complexity:

- **Negative:** 1-2 stars (15% of dataset, 21,048 reviews)
- **Neutral:** 3 stars (20% of dataset, 28,064 reviews)
- **Positive:** 4-5 stars (65% of dataset, 91,210 reviews)

This distribution reflects typical MOOC review patterns where positive feedback predominates. The class imbalance presents a realistic challenge for model development.

B. Data Preprocessing Pipeline

Given the noisy nature of user-generated content, we implemented a comprehensive preprocessing pipeline:

1) Text Cleaning:

- 1) **Contraction Expansion:** Converting informal contractions (e.g., "don't" → "do not") to normalized forms
- 2) **Case Normalization:** Converting all text to lowercase for consistency
- 3) **URL Removal:** Eliminating embedded hyperlinks using regex patterns
- 4) **Special Character Removal:** Removing non-alphabetic characters while preserving spaces
- 5) **Email and Mention Removal:** Stripping email addresses and social media mentions
- 6) **Whitespace Normalization:** Reducing multiple spaces to single spaces

2) Linguistic Processing:

- 1) **Tokenization:** Splitting text into individual tokens using NLTK's word_tokenize
- 2) **Stopword Removal:** Eliminating common words (e.g., "the", "is", "at") that carry minimal sentiment information
- 3) **Lemmatization:** Reducing words to their base forms using WordNet lemmatizer (e.g., "running" → "run", "better" → "good")

This preprocessing pipeline reduced vocabulary size by approximately 40% while preserving semantic content, improving both model efficiency and generalization.

C. Feature Extraction

We employed distinct feature extraction strategies for classical ML and deep learning approaches:

1) *TF-IDF Vectorization:* For classical machine learning models, we utilized TF-IDF with the following configuration:

- **Max Features:** 5,000 (top features by importance)
- **N-gram Range:** (1,2) capturing unigrams and bigrams
- **Min Document Frequency:** 5 (reducing noise from rare terms)
- **Max Document Frequency:** 0.85 (excluding overly common terms)
- **Sublinear TF:** Enabled (logarithmic term frequency scaling)

This configuration balances expressiveness and computational tractability, capturing both individual terms and contextual phrases.

2) *BERT Embeddings:* For the transformer-based approach, we used DistilBERT, a distilled version of BERT offering 97% of BERT's performance with 40% fewer parameters:

- **Model:** distilbert-base-uncased (66M parameters)
- **Max Sequence Length:** 128 tokens (covering 95% of reviews)
- **Tokenization:** WordPiece tokenization with BERT vocabulary (30,522 tokens)
- **Embeddings:** 768-dimensional contextual embeddings

Unlike TF-IDF, BERT captures contextual semantics, understanding that "not good" differs from "good" through bidirectional attention mechanisms.

D. Model Architectures

1) *Logistic Regression:* A linear classifier serving as a baseline:

- **Solver:** lbfgs (limited-memory BFGS)
- **Max Iterations:** 1,000
- **Regularization:** L2 (Ridge), C=1.0
- **Multi-class:** One-vs-Rest strategy

2) *Naive Bayes:* Probabilistic classifier based on Bayes' theorem:

- **Variant:** Multinomial Naive Bayes (suitable for discrete features)
- **Smoothing:** Laplace smoothing (alpha=1.0)
- **Assumption:** Conditional independence of features given class

3) *Random Forest:* Ensemble method combining multiple decision trees:

- **Number of Trees:** 200
- **Max Depth:** 50 (preventing overfitting)
- **Min Samples Split:** 10
- **Min Samples Leaf:** 4
- **Max Features:** sqrt(n_features)
- **Bootstrap:** Enabled with out-of-bag evaluation

Hyperparameters were optimized using GridSearchCV with 5-fold cross-validation.

4) *BERT Fine-tuning:* Transfer learning approach fine-tuning pre-trained DistilBERT:

- **Base Model:** distilbert-base-uncased
- **Classification Head:** Fully connected layer (768 → 3)
- **Dropout:** 0.1 (regularization)
- **Optimizer:** AdamW (learning rate: 2e-5)
- **Batch Size:** 8 (training), 16 (evaluation)
- **Epochs:** 1 (sufficient for convergence on large dataset)
- **Warmup Steps:** 100
- **Weight Decay:** 0.01
- **Loss Function:** Cross-entropy loss

We employed a learning rate scheduler with linear warmup followed by linear decay to stabilize training.

E. Training Procedure

1) *Data Split:* The dataset was partitioned using stratified sampling to preserve class distributions:

- **Training Set:** 80% (112,258 reviews)
- **Test Set:** 20% (28,064 reviews)

Stratification ensured that each split maintained the original 15:20:65 class distribution.

2) *Class Imbalance Handling:* To address the positive class bias, we employed:

- 1) **Class Weights:** Inversely proportional to class frequencies
- 2) **Stratified Sampling:** Ensuring representative training batches
- 3) **Evaluation Metrics:** Emphasizing weighted F1-score over accuracy

3) Computational Infrastructure:

- **Hardware:** Intel Core i7, 16GB RAM, NVIDIA GTX 1650 (4GB VRAM)
- **Software:** Python 3.11, PyTorch 2.0, scikit-learn 1.3, Transformers 4.30
- **Training Time:**
 - Classical ML: 2-5 minutes
 - BERT (CPU): 16 hours
 - BERT (GPU): 1.5 hours

F. Evaluation Metrics

We employed multiple metrics to comprehensively assess model performance:

- **Accuracy:** Overall classification correctness
- **Precision:** True positives / (True positives + False positives)
- **Recall:** True positives / (True positives + False negatives)
- **F1-Score:** Harmonic mean of precision and recall
- **Weighted Metrics:** Accounting for class imbalance
- **Confusion Matrix:** Detailed error analysis
- **Inference Time:** Milliseconds per prediction (latency)

For production deployment, we prioritized inference time alongside accuracy, recognizing that real-time applications require sub-second response times.

IV. RESULTS AND ANALYSIS

A. Model Performance Comparison

Table I presents comprehensive performance metrics for all evaluated models.

TABLE I
MODEL PERFORMANCE COMPARISON

Model	Acc.	Prec.	Rec.	F1
Logistic Reg.	82.1%	0.82	0.81	0.81
Naïve Bayes	78.3%	0.79	0.77	0.77
Random Forest	85.1%	0.86	0.84	0.84
BERT	87.2%	0.87	0.86	0.86

BERT achieved the highest performance across all metrics, validating the effectiveness of transfer learning with contextual embeddings. Random Forest provided competitive performance with significantly lower computational requirements.

B. Per-Class Performance Analysis

Table II shows Random Forest performance broken down by sentiment class.

TABLE II
RANDOM FOREST PER-CLASS METRICS

Class	Precision	Recall	F1
Negative	0.89	0.92	0.90
Neutral	0.74	0.73	0.73
Positive	0.92	0.98	0.95

Key observations:

- **Positive Class:** Highest performance (F1=0.95) due to abundant training examples and distinct linguistic patterns
- **Negative Class:** Strong performance (F1=0.90) despite minority status, indicating distinctive negative sentiment markers
- **Neutral Class:** Weakest performance (F1=0.73), reflecting the inherent ambiguity of moderate sentiment and frequent misclassification as adjacent classes

C. Confusion Matrix Analysis

The confusion matrix for Random Forest (Fig. ??) reveals specific error patterns:

- 92% of negative reviews correctly classified
- 73% of neutral reviews correctly classified
- 98% of positive reviews correctly classified
- Primary confusion: Neutral reviews misclassified as positive (15%) or negative (10%)
- Minimal confusion between positive and negative classes (1-2%)

This pattern aligns with expectations: neutral sentiment occupies the decision boundary between positive and negative, making it inherently more challenging to classify.

D. Feature Importance Analysis

Analyzing Random Forest feature importance revealed the most influential terms for sentiment prediction:

Top Positive Indicators:

- excellent (importance: 0.15)
- great (0.12)
- amazing (0.11)
- love (0.08)
- best (0.08)

Top Negative Indicators:

- poor (0.10)
- waste (0.09)
- bad (0.08)
- terrible (0.06)
- disappointing (0.05)

These features demonstrate that learners employ strong, unambiguous language when expressing extreme sentiments, facilitating classification. Neutral reviews, conversely, use more moderate vocabulary ("okay", "decent", "acceptable"), explaining classification difficulties.

E. Computational Efficiency

Table III compares training time and inference latency.

Key findings:

- **Naïve Bayes:** Fastest training and inference, suitable for resource-constrained environments
- **Random Forest:** Optimal balance—5-minute training, sub-100ms inference, 85% accuracy
- **BERT:** Highest accuracy but requires GPU for practical training and 5× slower inference

For production deployment targeting real-time applications, Random Forest emerges as the preferred choice.

TABLE III
COMPUTATIONAL EFFICIENCY COMPARISON

Model	Training	Inference
Logistic Reg.	2 min	~50 ms
Naive Bayes	1 min	~30 ms
Random Forest	5 min	~100 ms
BERT	16 hrs (CPU)	500 ms

F. BERT vs. Classical ML Trade-offs

The 2.1% accuracy improvement from Random Forest (85.1%) to BERT (87.2%) comes with substantial computational costs:

- **Training Time:** 200× longer (5 min vs. 16 hrs on CPU)
- **Inference Latency:** 5× slower (100ms vs. 500ms)
- **Memory Footprint:** 10× larger (20MB vs. 250MB)
- **Hardware Requirements:** GPU beneficial vs. CPU sufficient

This analysis suggests a hybrid deployment strategy: Random Forest for real-time user-facing applications, BERT for batch processing and offline analysis where accuracy is paramount.

G. Error Analysis

Manual examination of misclassified reviews revealed common error patterns:

1) *Sarcasm and Irony*: "Great course if you enjoy wasting your time"—misclassified as positive due to "great course" despite negative intent. BERT showed marginally better handling of such cases.

2) *Mixed Sentiment*: "Excellent content but terrible platform"—genuinely neutral overall but contains strong positive and negative elements. Models struggled with such reviews.

3) *Domain-Specific Terminology*: "Challenging but rewarding"—"challenging" has negative connotation generally but positive in educational contexts. BERT's contextual understanding helped here.

4) *Short Reviews*: Reviews under 10 words (8% of dataset) showed 15% lower accuracy across all models due to insufficient context.

V. SYSTEM DEPLOYMENT

Beyond model development, we implemented a complete production system to demonstrate practical applicability.

A. REST API

We deployed a FastAPI-based REST service providing:

- **Single Prediction Endpoint:** Analyze individual reviews in real-time
- **Batch Prediction:** Process up to 1,000 reviews per request
- **CSV Upload:** Direct file upload for bulk analysis
- **Model Information:** Retrieve performance metrics and model metadata
- **Health Monitoring:** Service status checks

API Documentation: Interactive Swagger UI and ReDoc interfaces enable easy integration and testing.

B. Interactive Dashboard

A Streamlit-based web dashboard provides non-technical users with:

- **Single Review Analysis:** Paste text, get instant classification with confidence scores
- **Batch Processing:** Upload CSV files for bulk analysis with downloadable results
- **Visualization:** Word clouds, sentiment distributions, trend analysis
- **Model Comparison:** Side-by-side performance metrics
- **Dataset Statistics:** Interactive exploration of training data characteristics

C. Deployment Architecture

The system follows a modular architecture:

- 1) **Data Layer:** Raw and processed datasets with version control
- 2) **Model Layer:** Serialized models and vectorizers
- 3) **Service Layer:** FastAPI REST endpoints with async support
- 4) **Presentation Layer:** Streamlit dashboard for end-users
- 5) **Testing Layer:** Comprehensive unit tests achieving 85% coverage

This architecture enables independent scaling of components and facilitates continuous integration/deployment.

VI. DISCUSSION

A. Key Findings

Our experimental evaluation yields several important insights:

1) *Transformer Superiority*: BERT's 87.2% accuracy represents the state-of-the-art for this dataset, validating the effectiveness of pre-trained language models. The bidirectional attention mechanism enables understanding of context and negation that classical methods struggle with.

2) *Random Forest Viability*: Despite being a classical approach, Random Forest achieves 85.1% accuracy—only 2.1% below BERT—while offering significant practical advantages. For MSMEs with limited computational resources, this represents an excellent choice.

3) *Neutral Class Challenge*: The consistent underperformance on neutral sentiment across all models (73-76% F1) highlights a fundamental challenge. Neutral reviews occupy the decision boundary and often contain mixed sentiments, making them inherently ambiguous. Future work might employ aspect-based analysis to decompose such reviews.

4) *Class Imbalance*: Despite positive reviews comprising 65% of data, all models achieved reasonable performance on minority classes through class weighting and stratified sampling. However, collecting more neutral and negative examples would likely improve performance.

B. Practical Implications for MSMEs

Our system addresses real needs of MSMEs in educational technology:

1) *Time Savings*: Automating analysis of 140,000 reviews saves an estimated 2,000+ hours compared to manual processing, enabling focus on strategic improvements rather than data processing.

2) *Scalability*: The REST API architecture enables processing of unlimited reviews with horizontal scaling, growing with business needs without proportional cost increases.

3) *Actionable Insights*: Beyond classification, feature importance analysis identifies specific terms driving sentiment, enabling targeted course improvements.

4) *Cost-Effectiveness*: Open-source implementation eliminates licensing costs. Classical ML models run on standard hardware without GPU requirements.

C. Limitations

We acknowledge several limitations:

1) *Language Limitation*: Our system handles only English reviews. MOOC learners globally write in diverse languages, necessitating multilingual support for broader applicability.

2) *Binary Aspect Analysis*: We classify overall sentiment but don't decompose into aspects (instructor, content, platform). Aspect-based sentiment analysis would provide more granular insights.

3) *Temporal Dynamics*: Our approach treats all reviews equally, ignoring temporal trends. Recent reviews may better reflect current course quality than historical feedback.

4) *Static Models*: Models require retraining to adapt to evolving language patterns and new courses. An online learning approach could enable continuous adaptation.

5) *Sarcasm Detection*: Both classical and BERT models struggle with sarcasm and irony, which appear in approximately 3-5% of reviews. Specialized sarcasm detection could improve accuracy.

D. Generalizability

While developed for MOOC reviews, our framework generalizes to other domains:

- E-commerce product reviews
- Restaurant and hospitality feedback
- Software application reviews
- Customer service interactions

The preprocessing pipeline and model architectures require minimal domain-specific adaptation, primarily involving vocabulary and potentially retraining.

VII. CONCLUSION AND FUTURE WORK

This paper presented a comprehensive sentiment analysis framework for MOOC reviews, addressing the needs of MSMEs for scalable, automated feedback analysis. Through systematic evaluation of four approaches on 140,322 Coursera reviews, we demonstrated that:

- 1) BERT fine-tuning achieves state-of-the-art accuracy (87.2%) through contextual understanding

- 2) Random Forest provides an excellent accuracy-efficiency trade-off (85.1% accuracy, 100ms inference)
- 3) Neutral sentiment remains challenging across all approaches (73-76% F1)
- 4) Production deployment via REST API and dashboard enables real-world adoption

The 2.1% accuracy difference between Random Forest and BERT comes with 200× training time and 5× inference latency increases, suggesting that classical ML remains highly relevant for resource-constrained real-time applications.

A. Future Research Directions

We identify several promising directions for future work:

1) *Aspect-Based Sentiment Analysis*: Decomposing reviews into aspects (instructor, content, assignments, platform) with per-aspect sentiment would provide more actionable insights. This requires annotated aspect-level datasets and specialized model architectures.

2) *Multilingual Support*: Extending to languages beyond English using multilingual BERT (mBERT) or XLM-RoBERTa would broaden applicability to global MOOC ecosystems.

3) *Explainable AI*: Implementing attention visualization and LIME/SHAP explanations would increase model transparency, building trust with educational stakeholders.

4) *Temporal Modeling*: Incorporating review timestamps to track sentiment trends over course lifecycle and detect emerging issues in real-time.

5) *Recommendation Systems*: Leveraging sentiment analysis to build course recommendation systems, suggesting courses with consistently positive feedback in learner-specific areas.

6) *Cross-Platform Analysis*: Extending to other MOOC platforms (edX, Udacity, FutureLearn) to enable competitive benchmarking and identify platform-specific sentiment patterns.

7) *Active Learning*: Implementing active learning to efficiently collect labels for neutral and negative reviews, addressing class imbalance cost-effectively.

8) *Real-Time Stream Processing*: Developing stream processing pipelines for continuous analysis of incoming reviews with automatic alerting for sentiment drops.

B. Final Remarks

The democratization of education through MOOCs presents unprecedented opportunities for MSMEs but also challenges in understanding learner needs at scale. Our work demonstrates that modern NLP techniques, when appropriately engineered and deployed, can provide actionable insights that were previously accessible only through labor-intensive manual analysis. By open-sourcing our implementation, we hope to accelerate adoption and further research in educational data mining.

The balance between accuracy and computational efficiency remains a critical consideration for production systems. While transformer models represent the frontier of NLP, classical machine learning methods continue to offer compelling value

propositions for many applications. As hardware capabilities improve and model compression techniques advance, we anticipate that the accuracy-efficiency trade-off will increasingly favor deep learning approaches, making sophisticated sentiment analysis accessible to organizations of all sizes.

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