Two Outliers at BEA 2025 Shared Task: Tutor Identity Classification using DiReC, a Two-Stage Disentangled Contrastive Representation

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https://github.com/edutjie/DiReC

Abstract

This paper presents DiReC (Disentangled Contrastive Representation), a novel two-stage framework designed to address the BEA 2025 Shared Task 5: Tutor Identity Classification. The task involves distinguishing between responses generated by nine different tutors, including both human educators and large language models (LLMs). DiReC leverages a disentangled representation learning approach, separating semantic content and stylistic features to improve tutor identification accuracy. In Stage 1, the model learns discriminative content representations using cross-entropy loss. In Stage 2, it applies supervised contrastive learning on style embeddings and introduces a disentanglement loss to enforce orthogonality between style and content spaces. Evaluated on the validation set, DiReC achieves strong performance, with a macro-F1 score of 0.9101 when combined with a CatBoost classifier and refined using the Hungarian algorithm. The system ranks third overall in the shared task with a macro-F1 score of 0.9172, demonstrating the effectiveness of disentangled representation learning for tutor identity classification.

1 Introduction

This paper presents the Two Outliers Tutor Identification Systems for Track 5 of the BEA 2025 Shared Task (Kochmar et al., 2025). The goal of this task is to recognize which response belongs to which tutor. We were provided with responses from nine different tutors, including two human tutors (novice and expert) and seven different Large Language Models (LLMs) (Abdin et al., 2024; OpenAI et al., 2024; Grattafiori et al., 2024; Team et al., 2024; Jiang et al., 2023) using data from MRBench (Maurya et al., 2024). For each question, all tutors provided an answer, and the objective is to develop a model capable of distinguishing between these tutor identities based on their responses.

Conversational agents, especially those powered by LLMs, are increasingly used in education to support student learning through interactive and tutor-like dialogue (Wollny et al., 2021; Tack et al., 2023). These systems can generate human-like, context-aware responses, offering new opportunities for scalable and personalized instruction. However, determining whether these models truly behave like effective tutors remains a challenge (Tack and Piech, 2022; Tack et al., 2023). This shared task explores whether it is possible to distinguish between responses generated by different AI tutors and human tutors.

Recent research has shown that models can be fine-tuned using contrastive loss to create powerful and representative embeddings. Powerful embedding models such as Jina, mE5, and BGE (Sturua et al., 2024; Chen et al., 2024; Wang et al., 2024) that are performing well in MTEB are trained using this approach (Muennighoff et al., 2023; Enevoldsen et al., 2025). Although a more common method for classification tasks involves using cross-entropy loss (Mao et al., 2023) to fine-tune encoder models like BERT (Devlin et al., 2019), contrastive learning approaches that produce high-quality embeddings and use simple classifiers have been shown to outperform this traditional method. In some cases, they even surpass large decoder-based models on classification benchmarks (Hanif et al., 2025; Muhammad et al., 2025). Furthermore, training models with contrastive loss directly on a downstream task has also demonstrated strong performance (Khosla et al., 2020; Muhammad et al., 2025). Motivated by these findings, our work explores contrastive learning as a strategy for tutor identification.

Contrastive loss is widely used in self-supervised learning to pretrain large language models by pulling together augmented views of the same input (Chen et al., 2020; Tao et al., 2024). For supervised tasks, supervised contrastive loss (Khosla

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et al., 2020) extends this by using label information, treating all samples with the same label as positives. This leads to more discriminative representations for classification.

Building on this foundation, we propose DiReC, a two-stage Disentangled Contrastive Representation framework for tutor response modeling. The core idea is to separate each response into two latent spaces: one that captures content (semantics, structure, factuality), and another that captures style (tone, verbosity, lexical choices), which is especially important for distinguishing among tutors. In the first stage, we train the model to learn content representations useful for tutor classification. In the second stage, we introduce supervised contrastive learning to the style space, encouraging similiar representations across responses from the same tutor. By disentangling these factors, the model better captures tutor-specific traits while maintaining a coherent content backbone, improving both classification accuracy and interpretability.

2 System Overview

We propose a two-stage Disentangled Representation for Classification (DiReC) framework for tutor classification, which simultaneously learns content and style representations from text. The overall architecture is depicted in Figure 1.

2.1 Model Architecture

Given an input text sequence $x = (w_1, \dots, w_T)$, we first obtain contextualized token embeddings via a pretrained DeBERTa-v3-large encoder:

$$\boldsymbol{H} = \mathrm{Enc}_\theta(x) \in R^{T \times d}, \quad \boldsymbol{h} = \boldsymbol{H}_{[\mathrm{CLS}]} \in R^d .$$

Two parallel projection heads then map $\boldsymbol{h}$ into the content and style subspaces of dimension p:

$$\boldsymbol{c} = f_{\text{content}}(\boldsymbol{h}) \in R^p, \quad \boldsymbol{s} = f_{\text{style}}(\boldsymbol{h}) \in R^p.$$

The content embedding $\boldsymbol{c}$ is intended to capture relevant semantic information for the identification of the tutor, while the style embedding $\boldsymbol{s}$ captures stylistic traits. We concatenate these vectors and feed them to a linear classifier g over K tutor classes:

$$\boldsymbol{z} = g\big([\boldsymbol{c}; \boldsymbol{s}]\big) \in R^K, \quad \hat{y} = \arg\max_j z_j .$$

2.2 Two-Stage Training Procedure

Training alternates between two stages to disentangle style from content:

Stage 1 (Cross-Entropy Only). While contrastive loss is effective at capturing stylistic similarity, it does not explicitly enforce class separation nor provide a direct classification signal. Therefore, cross-entropy acts as a necessary foundation to learn robust content features before style-specific objectives are introduced.

In the first stage, we freeze the style head f_{style} and train the encoder Enc_θ, content head f_{content}, and classifier g using standard cross-entropy loss:

$$\mathcal{L}_{\mathrm{CE}} = -\frac{1}{N} \sum_{i=1}^{N} \log \frac{\exp(z_{i,y_i})}{\sum_{j=1}^{K} \exp(z_{i,j})},$$

where z_{ij} is the logit for sample i and class j, and z_{i,y_i} is the logit for the true class label y_i of sample i. This loss encourages the model to learn discriminative content representations that effectively differentiate tutors based on semantic and structural aspects of their responses.

Stage 2 (Joint Contrastive & Disentanglement). In the second stage, we unfreeze the style head and optimize it jointly with the rest of the model. We apply supervised contrastive loss on style embeddings to capture tutor-specific writing traits, encouraging embeddings from the same tutor to cluster regardless of content variation. Simultaneously, a disentanglement loss penalizes high similarity between content and style embeddings, preventing redundancy and promoting specialization of each representation. This joint training improves the model's ability to separately encode semantic content and stylistic nuances, enhancing both interpretability and classification performance.

- $\mathcal{L}_{\mathrm{SupCon}}$ is the supervised contrastive loss applied to style embeddings:

  $$\mathcal{L}_{\mathrm{SupCon}} = -\frac{1}{|\mathcal{P}|} \sum_{(i,j)\in\mathcal{P}} \log \frac{\exp\big(\boldsymbol{s}_i^\top \boldsymbol{s}_j / \tau\big)}{\sum\limits_{k \neq i} \exp\big(\boldsymbol{s}_i^\top \boldsymbol{s}_k / \tau\big)}.$$

  where $\mathcal{P}$ indexes all positive pairs sharing the same tutor label, and τ is a temperature hyperparameter.

  Unlike the original formulation by Khosla et al., which uses log-softmax over multiple positives and negatives per anchor, our version is simplified. Since the main supervision is already provided via cross-entropy classification, the contrastive loss acts as an auxiliary signal to refine stylistic clustering, making a lighter pairwise variant sufficient and more efficient.

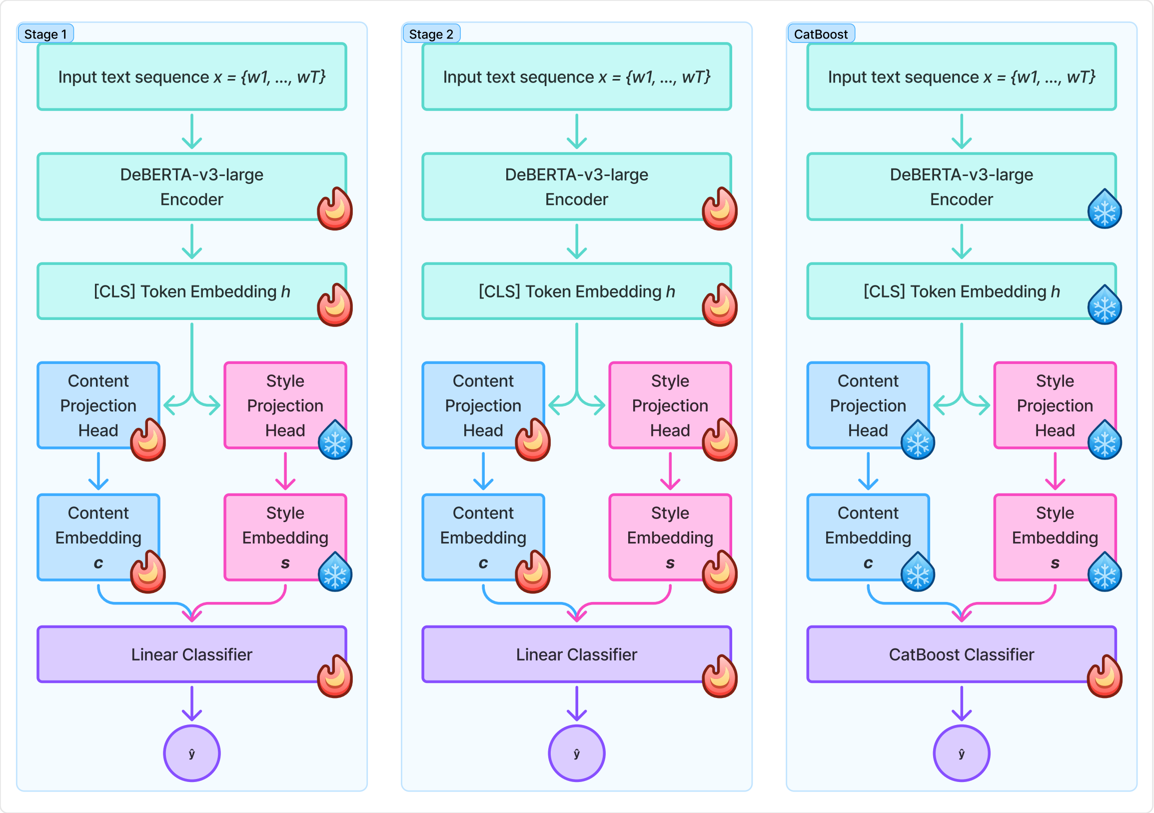


Figure 1: DiReC Architecture. Trainable components are marked with 🔥, while frozen components are indicated with ❄.

- $\mathcal{L}_{\text{dis}}$ is a cosine-based disentanglement loss that penalizes similarity between content and style embeddings:

$$\begin{aligned}\mathcal{L}_{\text{dis}} &= \frac{1}{N}\sum_{i=1}^{N}\left|\cos(\boldsymbol{c}_i, \boldsymbol{s}_i)\right| \\ &= \frac{1}{N}\sum_{i=1}^{N}\left|\frac{\boldsymbol{c}_i^{\top}\boldsymbol{s}_i}{\|\boldsymbol{c}_i\|\|\boldsymbol{s}_i\|}\right|.\end{aligned}$$

Finally we calculate all the loss using

$$\begin{aligned}\mathcal{L} = \lambda_{\text{CE}}\mathcal{L}_{\text{CE}} + \lambda_{\text{sty}}\,\mathcal{L}_{\text{SupCon}}(\{\boldsymbol{s}_i, y_i\}) \\ + \lambda_{\text{dis}}\,\mathcal{L}_{\text{dis}}(\boldsymbol{c}, \boldsymbol{s})\,.\end{aligned}$$

2.3 Experimental Setup

All experiments were conducted using a consistent set of hyperparameters (Table 3). At the onset of Stage 2, we halved the learning rate and enabled mixed-precision optimization (AdamW + `GradScaler`) to stabilize fine-tuning. The parameters are provided in Appendix A.

Unless stated otherwise, all single-stage experiments were trained for a total of 5 epochs. The two-stage DiReC model was initially set to train for 5 epochs during Stage 1 (content-only training with the style head frozen), followed by up to 5 additional epochs in Stage 2 (joint training with both heads unfrozen). In practice, however, the best validation checkpoint was achieved at epoch 6 (the first epoch of Stage 2). For clarity in the 3.1 subsection, we therefore refer to the two-stage model as effectively trained for 6 epochs in total.

At test time, we compute content and style embeddings jointly, concatenate them, and feed the resulting vector into the classifier g. The disentanglement enforced during training ensures that $\boldsymbol{c}$ and $\boldsymbol{s}$ capture complementary information, improving both generalization and interpretability in tutor prediction.

3 Result

3.1 Development

We conducted a series of experiments to validate the components of the DiReC framework. Table 1 summarizes the macro-F1 in the validation set for each setting.

Experiment	**Val. F1 (Macro)**
Single-stage DiReC	0.8720
Only content projection	0.8845
Only style projection	0.8692
Two-stage DiReC	0.9042
Two-stage DiReC + CatBoost classifier	0.9101

Table 1: Validation Macro-F1 scores for development experiments.

Single-Stage First, we trained the DiReC model in a single stage, which yielded a macro-F1 of 0.8720.

Projection-Head Ablation Next, we performed an ablation on the two projection heads to assess its standalone contribution. Training with only the content head for 5 epochs yielded a macro-F1 of 0.8845, whereas using only the style head under the same epochs fell to 0.8692. Moreover, when we extended the content-only model to 6 epochs—to match the total training steps of our two-stage strategy—its performance dropped further to 0.8730, indicating overfitting in the absence of style guidance. These results confirm that the content subspace carries the most of the classification signal, and naively prolonging content-only training can actually harm generalization.

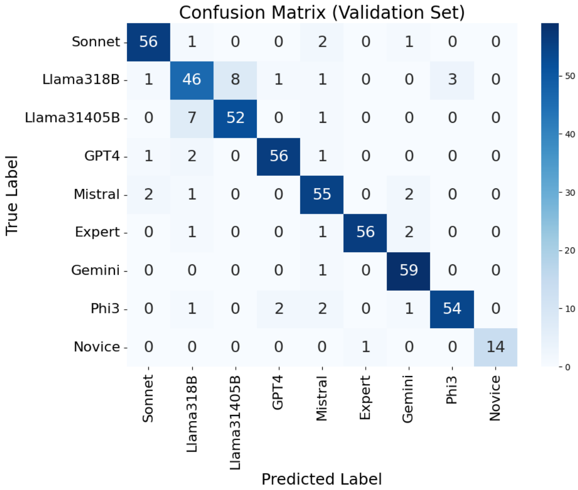
Two-Stage DiReC We observed that introducing the style projection head from the initial stage of training could potentially hinder the development of the content projection's discriminative capabilities. However, a naive extension of content-only training often led to overfitting. Consequently, we hypothesized that treating the style learning as a subsequent refinement phase could be beneficial. To address these limitations, we adopted the two-stage DiReC strategy (Section 2), introducing the style head only after the content pathway had converged. This staged training approach achieved a validation macro-F1 score of 0.9042, with the best model obtained at epoch 6—the first epoch of Stage 2. It outperformed both content-only baselines, which achieved scores of 0.8845 at epoch 5 and 0.8730 at epoch 6, establishing our strongest benchmark among purely neural network models.

CatBoost on Learned Embeddings Finally, we replaced the model's linear classifier with a CatBoost classifier (Prokhorenkova et al., 2019) trained on the concatenated style||content embeddings. This hybrid approach further improved validation macro-F1 to 0.9101.

Embedding Clustering Evolution Figures 2a–2c visualize the t-SNE projections of content embeddings at epochs 1, 3, and 6. Early in training (Figure 2a), tutor clusters overlap greatly. By epoch 3 (Figure 2b), distinct clusters begin to form, and by epoch 6 (Stage 2) (Figure 2c) each tutor's content representations occupy tight, well-separated regions. This suggest that DiReC has effectively learned to represent tutor-specific content characteristics.

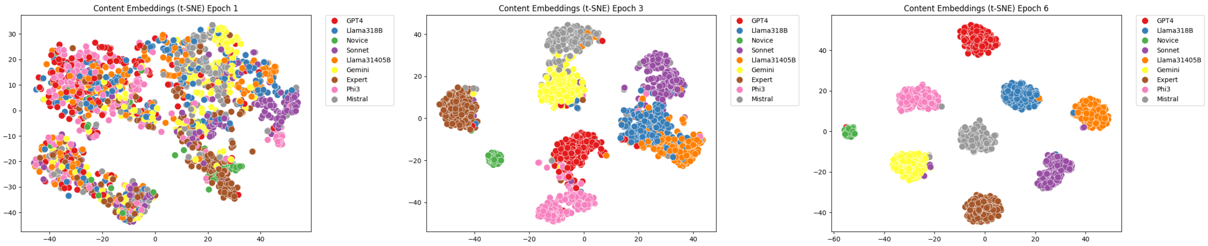
Validation Confusion Matrix Analysis Figure 3 shows the two-stage DiReC + CatBoost classifier confusion matrix on the validation set. The strong diagonal indicates high overall classification accuracy, with most tutor identities being correctly predicted. However, some misclassification between different tutor identities is observable.

The highest confusion occurs between Llama3.1-8B and Llama3.1-405B. Specifically, 8 instances of Llama3.1-8B are misclassified as Llama3.1-405B, and 7 instances of Llama3.1-405B are misclassified as Llama3.1-8B. This is likely attributable to the inherent similarity in response styles and content patterns originating from the same Llama model family. Nevertheless, the majority of tutors are classified with high precision and recall, with the primary challenge lying in distinguishing between closely related model variants, highlighting the effectiveness of the disentangled representations.



True Label \ Predicted Label	Sonnet	Llama318B	Llama31405B	GPT4	Mistral	Expert	Gemini	Phi3	Novice
Sonnet	56	1	0	0	2	0	1	0	0
Llama318B	1	46	8	1	1	0	0	3	0
Llama31405B	0	7	52	0	1	0	0	0	0
GPT4	1	2	0	56	1	0	0	0	0
Mistral	2	1	0	0	55	0	2	0	0
Expert	0	1	0	0	1	56	2	0	0
Gemini	0	0	0	0	1	0	59	0	0
Phi3	0	1	0	2	2	0	1	54	0
Novice	0	0	0	0	0	1	0	0	14

Figure 3: Validation confusion matrix for the two-stage DiReC + CatBoost classifier.



(a) Epoch 1 (b) Epoch 3 (c) Epoch 6

Figure 2: Evolution of content-embedding clusters over training.

3.2 Submission

Each conversation in the dataset contains K utterances, each from a different tutor, requiring a one-to-one mapping between utterances and tutor labels. However, our CatBoost classifier predicts labels independently, which can result in duplicate tutor assignments.

To enforce uniqueness, we apply the Hungarian algorithm as a post-processing step (Crouse, 2016). For each conversation g, we create a $K \times K$ probability matrix $\mathbf{P}^{(g)}$, where $P_{ij}^{(g)}$ is the predicted probability that utterance i belongs to tutor j. We seek the assignment σ^* that maximizes the total confidence:

$$\sigma^* = \arg\max_{\sigma \in S_K} \sum_{i=1}^{K} P_{i,\sigma(i)}^{(g)}$$

Since SciPy's `linear_sum_assignment`[1] minimizes cost, we negate the probabilities to form a cost matrix $\mathbf{C}^{(g)}$, with $C_{ij}^{(g)} = -P_{ij}^{(g)}$. This ensures a unique, high-confidence mapping between utterances and tutor labels. This procedure refines the initial probabilistic predictions from the classifier to adhere to the structural constraint of the problem for each conversation.

Rank	Team	F1	Acc
1	Phaedru	0.9698	0.9664
2	SYSUpporter	0.9692	0.9657
3	**Two Outliers**	**0.9172**	**0.9412**

Table 2: Final leaderboard results of the shared task. Our team, Two Outliers, finished in third place.

The predictions from the two-stage DiReC model combined with the CatBoost classifier, further refined using the linear sum assignment strategy, were submitted to the official Codabench leaderboard. This approach achieved a final macro-F1 score of $\mathbf{0.9172}$, placing third in the shared task, as shown in Table 2.

4 Conclusion

In this work, we proposed DiReC, a two-stage framework that leverages disentangled contrastive representation learning for the task of tutor identity classification. Our approach separates content and style embeddings to capture both semantic and tutor-specific stylistic characteristics, resulting in improved classification accuracy and interpretability. Empirical evaluations on the BEA-2025 Shared Task data show that the two-stage DiReC model outperforms single-stage baselines and benefits from contrastive refinement and disentanglement. Additionally, incorporating a CatBoost classifier and applying a Hungarian algorithm for structured post-processing further enhanced performance, culminating in a top-three placement in the official leaderboard. These results highlight the potential of disentangled representation learning in modeling nuanced tutor behavior across human and AI-generated responses.

Limitations

Due to time and computational constraints, we did not perform thorough hyperparameter tuning. Several important parameters, including the contrastive temperature, the weights for the cross-entropy loss, style loss, and disentanglement loss, were chosen heuristically without extensive validation. Additionally, core training settings such as the learning rate, batch size, and number of training epochs were fixed throughout our experiments. These parameters may significantly influence model performance, and future work could focus on systematically tuning them to achieve further improvements.

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[1] `https://docs.scipy.org/doc/scipy/reference/generated/scipy.optimize.linear_sum_assignment.html`

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A Appendix

Hyperparameter	**Value**
Maximum sequence length (`MAX_LEN`)	256 tokens
Batch size (`BATCH_SIZE`)	32
Initial learning rate (LR)	2×10^{-5}
Encoder embedding size (EMBED_SIZE)	1024
Projection dimension (PROJ_SIZE)	256
Contrastive temperature (τ)	0.07
CE loss weight (λ_{CE})	1.0
Style loss weight (λ_{sty})	0.3
Disentanglement weight (λ_{dis})	0.1

Table 3: Hyperparameter settings for all DiReC experiments.