Deep Learning Techniques for Automatic Short Answer Grading: Predicting Scores for English and German Answers

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Abstract We investigate and compare state-of-the-art deep learning techniques for *Automatic Short Answer Grading*. Our experiments demonstrate that systems based on the *Bidirectional Encoder Representations from Transformers* (BERT) [1] performed best for English and German. Our system achieves a Pearson correlation coefficient of 0.73 and a Mean Absolute Error of 0.4 points on the Short Answer Grading data set of the University of North Texas [2]. On our German data set we report a Pearson correlation coefficient of 0.78 and a Mean Absolute Error of 1.2 points. Our approach has the potential to greatly simplify the life of proofreaders and to be used for learning systems that prepare students for exams: 31% of the student answers are correctly graded and in 40% the system deviates on average by only 1 point out of 6, 8 and 10 points.

Keywords Automatic short answer grading · Artificial intelligence in education · Natural language processing · Deep learning

1 Introduction

The research area "AI in Education" addresses the application and evaluation of Artificial Intelligence (AI) methods in the context of education and training [3]. One of the main focuses of this research is to analyze and improve teaching and learning processes. Many educational institutions–public and private–already conduct their courses and examinations online. This means that student examinations and their assessments are already available in digital, machine readable form, offering a wide range of analysis options. An exam typically consists of multiple choice and free text questions. While answers to multiple choice questions can easily be evaluated by machines, the evaluation of free text answers still requires tedious manual work by the examiners.

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The focus of our paper is on Automatic Short Answer Grading (ASAG) with deep learning, i.e., the evaluation and further development of various deep learning state-of-the-art approaches to automatically evaluate free text answers. We investigate the following two architectures to compare a student answer with a given model answer and to predict an evaluation in the form of a score:

- Our *feature extraction architecture* uses general pre-trained sentence embeddings in a high-dimensional semantic vector space as input values and predicts a score using a linear classifier.
- Our *fine-tuning architecture* is based on a pretrained deep learning model, which supplemented by a linear layer is adapted to the specific task of ASAG. In contrast to our *feature extraction architecture*, the parameters of the embeddings are tuned as well.

A data set with manually graded exams and sample solutions from the area *Business Administration* of a German bachelor's program serves to optimize models and evaluate quality. To evaluate and classify the findings in the context of current research, an English data set from the University of North Texas with questions from the undergraduate studies of *Computer Science* is also used.

In the next section, we present the latest approaches of other researchers for ASAG. Section 3 describes our experimental setup. Section 4 characterizes the models which we evaluate and compare. Our experiments and results are outlined in Sect. 5. We conclude our work in Sect. 6 and suggest further steps.

2 Related Work

A good overview of rule-based and statistical-based approaches in ASAG before the deep learning era is given in [4]. Newer publications are based on *bag-of-words*, a procedure based on term frequencies [5, 6]. The latest trend which has proven to outperform traditional approaches is to use neural network-based embeddings, such as *Word2vec* [7]. [8] have developed *Ans2vec*, a *feature extraction architecture*-based approach. It is based on combine-skip sentence embedding [9] and logistic regression. They evaluated their concept with a non-public data set from the University of Cairo, the SciEntsBank data set [10], and the English data set of the University of North Texas [2]. This English data set of the University of North Texas–like the German data set of our university–contains scored student answers. Consequently, it is a comparative data set which is also evaluated in the experiments of this paper. Like us, [8] use the Pearson correlation coefficient for evaluation. They report a best value of 0.63 on the data of the University of North Texas. [11] use a data set from the Hewlett Foundation[1] to compare different approaches based on deep learning models, including a *fine-tuning architecture* based on the *Bidirectional Encoder Representations from Transformers* (*BERT*) [1]. [12] and [13] deal in their work exclusively

[1] https://www.kaggle.com/c/asap-sas.

with *BERT fine-tuning architectures*. In their work, answers are categorized into 3 classes–there is no point-based grading. *BERT* also provides the basis for our *fine-tuning architecture,* but we focus on point-based grading. [14] and [15] developed systems which classify German student answers as "correct" and "wrong"—based on traditional features such as lemmas.

Our contributions are the analysis of deep learning architectures for transfer learning on an English and a German data set. This includes the investigation of multilingual deep learning models. We are the first to examine point based ASAG of questions with variable maximum score.

3 Experimental Setup

In this section we describe our evaluation metrics and corpora.

3.1 Evaluation Metrics

As in related literature, we evaluate our results with the *Pearson correlation coefficient* [16], the *Mean Absolute Error* and the *Root Mean Square Error (RMSE).*

Pearson Correlation Coefficient. The Pearson correlation coefficient (*Pearson*) indicates how strong the linear relationship between predictions and target values is. If the value is close to 0, there is no correlation; if it is close to 1, there is a strong correlation. The Pearson correlation coefficient is the normalized covariance. Therefore, it is independent of the scaling used in the data.

Mean Absolute Error. The Mean Absolute Error *(MAE)* is calculated from the average deviations of the prediction from the target value. It depends on the units and scaling in the evaluated data set.

Root Mean Square Error. Unlike Mean Absolute Error, in the Root Mean Square Error *(RMSE)* the error is squared, and the square root of the mean square deviation is considered. Squaring the error results in strong deviations being weighted more heavily than small ones.

3.2 Corpora

We evaluate our experiments with a German and an English data set which are compared in Table 1. To provide insights into both data sets,[2] Tables 2 and 3 indicate

[2] Questions and answers were modified for the German data set due to confidentiality.

Table 1 Information of the data sets

	German	English
Subject	Business administration	Data structures
#questions with model answer	233	87
#answers (total)	3,560	2,442
#answers per question	15.4	28.1
Ø length of answer (#words)	87.6	18.4
Maximum scores (in points)	6/8/10	5
Annotated model answer	yes	no

Table 2 Original sample question and answers from the English data set

Question	What is a variable?
Model answer	A location in memory that can store a value
Example: Answer 1	A variable is a location in memory where a value can be stored
Grading: Answer 2	5 of 5 points
Example: Answer 2	Variable can be an integer or a string in a program
Grading: Answer 2	2 of 5 points

Table 3 Modified and translated sample question and answers from the German data set

Question	• Explain: What is the role of models in business administration? • Explain how statements of a model can be distinguished from each other according to the completeness of the information
Model answer	In business administration, models are used to obtain, formulate, and test knowledge from the operational context (2 points). Statements with complete information are statements with certainty (3 points). Statements with incomplete information are statements under uncertainty or risk (3 points)
Example: Answer 1	(a) In business administration, models are used to explain, describe, forecast and design macro- and microeconomic phenomena (b) Complete information represents security. Incomplete information represents uncertainty and risk
Grading: Answer 2	8 of 8 points
Example: Answer 2	Models are used for information. Explanatory model: Explains reasons in the company, e.g., employee motivation. Descriptive model: describes business phenomena in the company, e.g., accounting which records the entire flow of money in the company. Decision model: here different information is combined with each other. For example, the optimal order quantity. This depends on various factors
Grading: Answer 2	2 of 8 points

for each data set, a typical question, the corresponding model answer and two student answers. One of them was given the full score, the other one is a rather weak answer.

3.3 English Short Answer Grading Data Set

The short answer grading data set of the University of North Texas [2] contains 87 questions with corresponding model answer and on average 28.1 evaluated answers per question about the topic *Data Structures* from the undergraduate studies. The questions are rather short and are not divided into sub-questions. They can usually be answered in only one sentence and no knowledge transfer is required.

3.4 German Short Answer Grading Data Set

The German data set is taken from an online exam system in the learning management system *Moodle*.[3] It contains 233 questions with corresponding model answer and on average 15.4 evaluated answers per question from the bachelor module *Business Administration*. A special feature of the German data set is that the maximum achievable score varies from question to question. Depending on the question a maximum of 6, 8 or 10 points can be achieved. Another feature is that the model answers include annotations with the criteria for grading performance. Many model answers contain only short hints for the corrector, so that in many cases additional background knowledge is needed for correction in addition to the model answer. A question usually consists of several sub-questions on a common topic and, in addition to the pure reproduction of knowledge. In many cases knowledge transfer is expected from the students.

4 Techniques

This paper describes and compares the following two architectures for transfer learning: A *feature extraction architecture* and a *fine-tuning architecture*.

4.1 Feature Extraction Architecture

This architecture is based on the *Ans2vec* approach described by [8]: The model answer and the student answer are first converted into the two embedding vectors

[3] https://moodle.org.

MA and *SA*. Then the dot product and the absolute difference of the two embedding vectors are calculated and concatenated. The result of the concatenation is the input vector for a linear model to predict the score.

Ans2vec-Skip-Logit-Baseline. [8] use combine-skip vectors for the embeddings and logistic regression as a classifier (*Ans2vec-Skip-Logit-Baseline*). Since no combine-skip embeddings are available for German, we evaluated this model only on English.

Ans2vec-MUSE-Logit. *Ans2vec-MUSE-Logit* refers to a model that corresponds to *Ans2vec-Skip-Logit-Baseline*, but for sentence embedding the *Multilingual Universal Sentence Encoder* (*MUSE*) [17] is used.

Ans2vec-Skip-SVM. *Ans2vec-Skip-SVM* refers to a model that corresponds to *Ans2vec-Skip-Logit-Baseline*, but for the classification a *Support Vector Machine* (*SVM*) is used [18]. Due to the lack of German combine-skip embeddings, we also evaluated this model only on the English data set.

Ans2vec-MUSE-SVM. *Ans2vec-MUSE-SVM* refers to a model that corresponds to *Ans2vec-Skip-Logit-Baseline*, but for the sentence embedding the *MUSE* is used and for the classification an *SVM*.

4.2 Fine-Tuning Architecture

This architecture is based on *BERT* [1] from the family of transformer models. We supplemented *BERT* with a linear regression layer that provides a prediction of the score given an answer. The model takes the model answer and the student answer without prior embedding as input, separates the model answer and the student answer with a *separator token* and performs a tokenization into *word pieces*. Since in our German and English data sets the scores are not only discrete integer values, this approach uses regression instead of classification. Our evaluated *BERT* models are characterized in the following sections.

BERT-EN. *BERT-EN* refers to the English BERT[4] published by [1].

BERT-DE-Deepset. *BERT-DE-Deepset* refers to a German *BERT* model provided by Deepset GmbH. The model is trained on Wikipedia and Open Legal Data.[5]

BERT-Multilingual. *BERT-Multilingual* refers to a multilingual *BERT* model[6] which is published by Google, supports 104 languages and is trained on Wikipedia.

[4] https://github.com/google-research/bert.

[5] https://deepset.ai/german-bert.

[6] https://github.com/google-research/bert/blob/master/multilingual.md.

5 Experiments and Results

Randomization and splitting of the data sets into training, validation and test data using 5-fold cross-validation is performed in all experiments to determine most accurate models for the German and English data as shown in Table 4. After the most accurate models for the German and English data set were determined, we evaluated them on the held-out test set.

5.1 English Automatic Short Answer Grading

The results of the experiments with the English data set and their relative improvements compared to *Ans2vec-Skip-Logit-Baseline* are shown in Table 5. For comparison, the first line also contains the values published by [8]. Since they do not provide further details on the implementation, parameters, and the procedure for evaluating the model, the reasons for deviation cannot be further analyzed. If instead of the combine-skip embeddings the *MUSE* embeddings are used, the results improve, and the training effort is reduced considerably. With only 512 dimensions, the *MUSE* embeddings are significantly more compact than the combine-skip vectors with 4,800 dimensions. The *Ans2vec* model also provides better predictions if the linear regression is replaced by an *SVM* classifier. However, the *BERT* models provide the best

Table 4 Preparation of data sets for cross-validation

Data set	Portion	German	English
Total	100%	3,560	2,442
Cross validation	80%	2,848	1,953
Test (held-out)	20%	712	489
Cross validation	100%	2,848	1,953
Training	80%	2,278	1,953
Validation	20%	570	391

Table 5 Basic experiments with the English data set

Model	Pearson	RMSE	MAE
[7]	0.63	0.91	–
Ans2vec-Skip-Baseline	0.33 (+0.0%)	1.27 (+0.0%)	0.73 (+0.0%)
Ans2vec-Skip-SVM	0.49 (+48.6%)	1.09 (−14.0%)	0.60 (−16.8%
Ans2vec-MUSE-Logit	0.38 (+13.6%)	1.24 (−2.2%)	0.69 (−4.5%)
Ans2vec-MUSE-SVM	0.56 (+67.5%)	1.02 (−19.1%)	0.56 (−23.7%)
BERT-EN	**0.79** (+138.5%)	**0.69** (−45.3%)	**0.41** (−43.3%)
BERT-Multilingual	0.79 (+137.1%)	0.70 (−44,6%)	0.43 (−44,6%)

results. *BERT-EN* is the best of all models, but *BERT-Multilingual* provides only slightly worse numbers. With a *Pearson* of 0.79, we see that the scores predicted by the *BERT-EN* model have a strong linear relationship with the scores decided by the human corrector. On average, the evaluation of an answer by the model deviates by 0.41 points (see *MAE*). The *RMSE*, which weighs more strong deviations, also has the lowest number in this model. Compared to the numbers published by [8], the *BERT-EN* model achieves a relative improvement of more than 25% in *Pearson* and 23% in *RMSE*.

5.2 German Automatic Short Answer Grading

The results of the experiments with the German data set are shown in Table 6. Comparing these results with those of the evaluation of the English data set, only *Pearson* may be used. *MAE* and *RMSE* depend on the scaling of the score, which is different for both data sets. Looking at the linear correlation, one will notice that *Ans2vec-MUSE-Logit* performs slightly better on the German data set, while *Ans2vec-MUSE-SVM* performs slightly better on the English data set. The results of *BERT* on the German data set are only slightly worse than on the English data, even if the German exam questions are considerably more complex and extensive.

The German data set also demonstrates that the *BERT fine-tuning architecture* produces significantly better results. Again, the monolingual *BERT* model—in this case the *BERT-DE-DBMDZ*—is slightly better than the multilingual model. The best model is *BERT-DE-DBMDZ* which—with a *Pearson* of 0.75—shows a strong linear relationship between prediction and actual scores. The model's prediction deviates by 1.30 points from the human corrector's grading (see *MAE*). Compared to *Ans2vec-MUSE-Logit*, *Pearson* could be improved by 90% relative. The *RMSE* and *MAE* are almost 31% lower than the numbers of the *Ans2vec-MUSE-Logit* model.

Table 6 Basic experiments with the German data set

Model	Pearson	RMSE	MAE
Ans2vec-MUSE-Logit	0.39	2.52	1.87
Ans2vec-MUSE-SVM	0.44 (+11,2%)	2.68 (+6,6%)	1.90 (+1,9%)
BERT-DE-Deepset	0.74 (+89.2%)	1.76 (−30.3%)	1.31 (−29.7%)
BERT-DE-DBMDZ	**0.75** (+90.2%)	**1.75** (−30.6%)	**1.30** (−30.6%)
BERT-multilingual	0.71 (+81.4%)	1.83 (−27.4%)	1.38 (−26.3%)

Table 7 Further experiments with the German data set

Model	Pearson	RMSE	MAE
BERT-DE-DBMDZ	0.75	1.75	1.30
Annotations removed	0.74 (−1.4%)	1.78 (+2.0%)	1.31 (+1.3%)
Max. score annotated	**0.75** (+0.8%)	**1.73** (−0.9%)	**1.28**(−1.7%)

Table 8 Final results on the unseen text sets

Language	Pearson	RMSE	MAE
English	**0.73** (+15.5%)	**0.72** (−20.9%)	**0.42**
German	**0.78**	**1.62**	**1.19**

5.3 Experiments with Removed and Added Annotations on the German Data Set

We removed the annotations with the criteria for grading (e.g., "(2 points)", see Table 3) and re-evaluated the best model *BERT-DE-DBMDZ*. Additionally, we added annotations for the maximum achievable score of each question to the model answers (e.g., "maximum 8 points"). The results of the further experiments compared to *BERT-DE-DBMDZ* can be found in Table 7. Removing the annotations reduces the quality of the model's predictions, adding the annotations slightly improves them.

5.4 Final Results

After the most accurate models for the German and English data set were determined, we evaluated them on the unseen *test set*. As shown in Tables 5 and 7, *BERT-EN* is the best model on the English data set and *BERT-DE-DBMDZ (Maximum score annotated)* on the German data set. The results of the final evaluation are illustrated in Table 8. For English, the relative improvement compared to [8] is also shown.

6 Experiments and Results

We investigated and compared state-of-the-art deep learning techniques for *Automatic Short Answer Grading*. With our *BERT* models we achieved a significant performance improvement compared to our baseline system and related work. Our system achieves a Pearson correlation coefficient of 0.73 and a Mean Absolute Error of 0.4 points on the Short Answer Grading data set of the University of North Texas [2]. On our German data set we report a Pearson correlation coefficient of 0.78 and a Mean Absolute Error of 1.2 points. The result on our English and German data sets were comparable even though the German data set contains more complex questions and has variable maximum scores.

Future work will include an analysis of what types of questions and answers the system still has issues and how we can tackle them. For example, examination questions often contain sub-questions. It could be evaluated whether their separation into individual questions leads to better predictions. We also plan to analyze to what extent the quality of the model improves by training the model on further subject-specific corpora such as lecture notes or textbooks as suggested by [19]. The developed model could also be used as a warning system: The system detects when a human corrector's grading significantly deviates from the model (e.g., by a defined threshold) and initiates further steps, e.g., the transfer of the relevant student answer and correction to a further review process. Furthermore, we plan to investigate the time savings by our automation. For example, our first more detailed analyses of the results of the German data set indicate that in 31% of all cases the score can be just accepted. In 39.6% of the cases the suggested score only needs to be corrected 1 point up or down out of 6, 8 and 10 points. This means that in 70.6% the total score does not have to be corrected at all or only by 1 point, which could lead to significant time savings in the correction process and to be used for learning systems that prepare students for exams [20].

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