Title page: EEDG/CE 6302 Lab Report 7
CE6302, Embedded Systems, 302 Laboratory - 83204
Lab Topic: TinyML 4.1 Signal Classification Using Spectral Features
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1. Objective:

Purpose: The purpose of lab 7 is to use TinyML to classify the ECG(Electrocardiography) signal, with different signal processing methods during preprocessing, and using different neural network architecture to train the models. After testing models, the performance of each model is shown and compared.

Methods used: In the preprocessing step, spectral features and spectrogram are used respectively to process signals. While training models, DNN, and 1D CNN, 2D CNN neural network architecture are deployed respectively.

Results: After training and testing the models, the performance of each model is different. Based on the accuracy and loss, the 2D CNN neural network architecture has better performance, and the spectrogram signal processing method has better performance.

Software used: Edge Impulse CLI, Hugging Face.

Major Conclusions: The signal processing method during preprocessing affects the way to extract features and ultimately makes an important impact to the performance of the trained model. When working with ECG signals, and other signals with dynamic frequency content over time, using a spectrogram over traditional spectral features will capture the signal features much better. And choosing neural network architecture will affect the model's performance as well, in this lab, 2D CNN provides the best performance.

2. Introduction:

2.1 Hardware and Software Background Information
Software Background Information: Edge Impulse is ushering in the future of embedded machine learning by empowering developers to create and optimize solutions with real-world data. It makes the process of building, deploying, and scaling embedded ML applications easier and faster than ever, unlocking massive value across every industry, with millions of developers making billions of devices smarter.
Hugging Face: The Hugging Face Hub is a platform with over 900k models, 200k datasets, and 300k demo apps (Spaces), all open source and publicly available, in an online platform where people can easily collaborate and build ML together. The Hub works as a central place where anyone can explore, experiment, collaborate, and build technology with Machine Learning.

2.2 Purpose of the Experiment
This lab exercise focuses on ECG signal classification using spectral features from a preprocessed dataset of filtered and segmented ECG data from 290 individuals in the PTB database. The goal is to

evaluate the performance of different Deep Neural Network (DNN) architectures and assess ESP32 performance at each architecture level using Edge Impulse.

2.3 Summary of the Experiment

After using two different signal processing methods(traditional spectral features, and Spectrogram Features), and three different neural network architectures(DNN, 1D CNN, 2D CNN) with preset parameters, we tested the result of each model, and compared them. Using spectrogram to process signals and extract features provides significant improvement on model performance over using spectral. And using 1D CNN and 2D CNN neural network architectures slightly improves the model performance.

2.4 Findings of the experiment

In preprocessing, spectrogram has significant improvement over spectral because it extracts additional features, the signal's frequency content changes over time. This makes it possible to train the model with high performance.
In choosing neural network architectures, 2D CNN has best accuracy, but has highest memory usage and latency, which may not be suitable for real-time embedded systems. However, 1D CNN has lower memory usage and lower latency. Despite the performance being slightly lower than 2D CNN, 1D CNN is the best NN to deploy to the embedded system. This implies that for embedded systems, we need to find the trade-off between model performance and hardware resource usage.

3. Explanation:

3.1 Experiment procedure

The procedure involves downloading and extracting the dataset from Hugging Face, which contains filtered and segmented ECG signals. The data is then imported into Edge Impulse, separating training and testing sets. Two main approaches are explored: Spectral Analysis and Spectrogram features.
For Spectral Analysis, the impulse is created using Spectral Analysis as the processing block and classification as the learning block. Spectral features are generated using default parameters. The classifier is configured with a low learning rate of 0.0005 to prevent overshooting, and training is performed for multiple cycles (ideally 30). A specific Neural Network architecture is designed and trained using the spectral features.
Similarly, for Spectrogram features, the process is repeated with Spectrogram as the processing block. The classifier is trained with a learning rate of 0.0005 for 7 cycles (due to Edge Impulse membership limitations). Another Neural Network architecture is designed and trained using the spectrogram features.
Part 2 then compares the performance of different models (DNN, 1D CNN, and 2D CNN) for the ESP32 platform. For the DNN, two dense layers with 60 neurons are used. The 1D CNN architecture includes a reshape layer, 1D convolution and pooling layers, dropout layers, and a flatten layer. The 2D CNN follows a similar structure but with 2D convolution layers.
Throughout the process, model testing is performed to evaluate accuracy. The overall objective is to compare the effectiveness of different feature extraction methods and neural network architectures for ECG signal classification on the ESP32 platform.

3.2 Experiment Images for Part 1

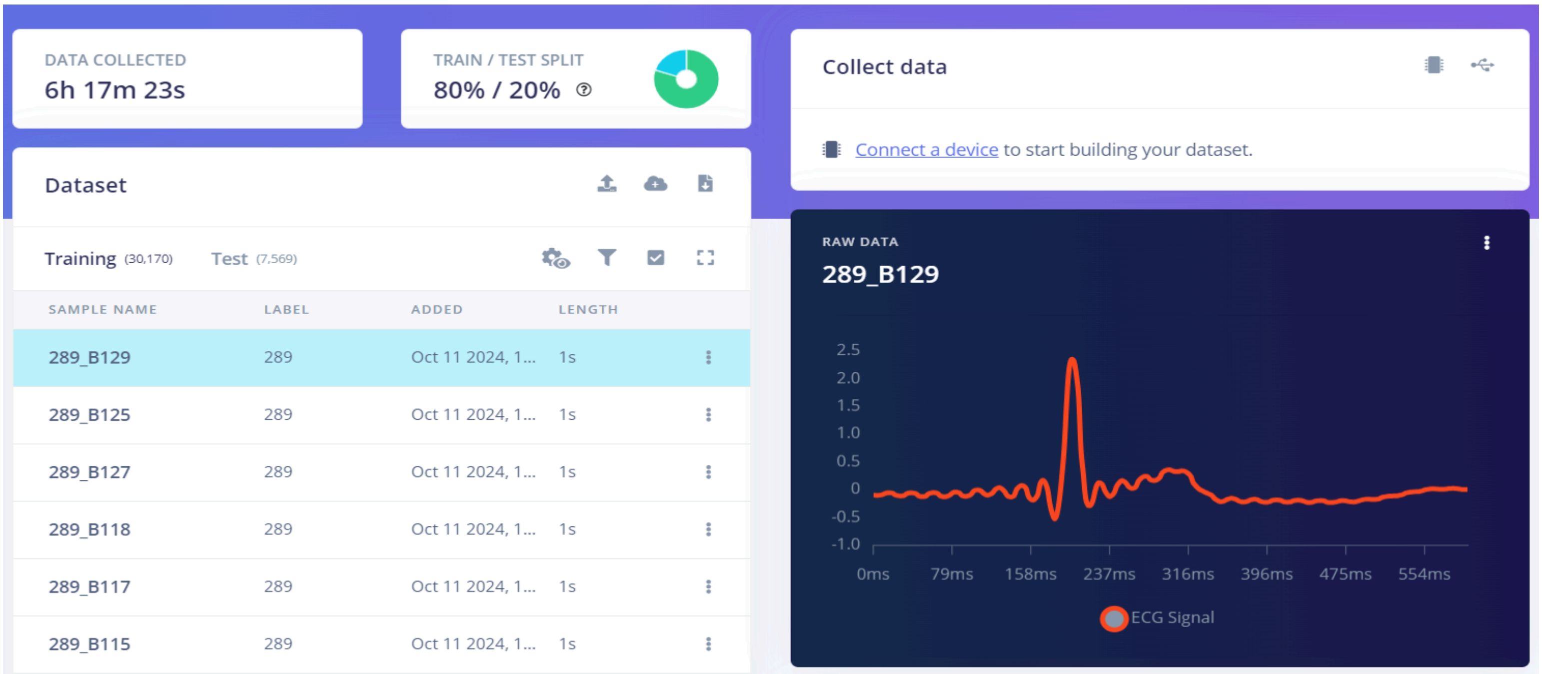


Image 3.2-1: Data Acquisition

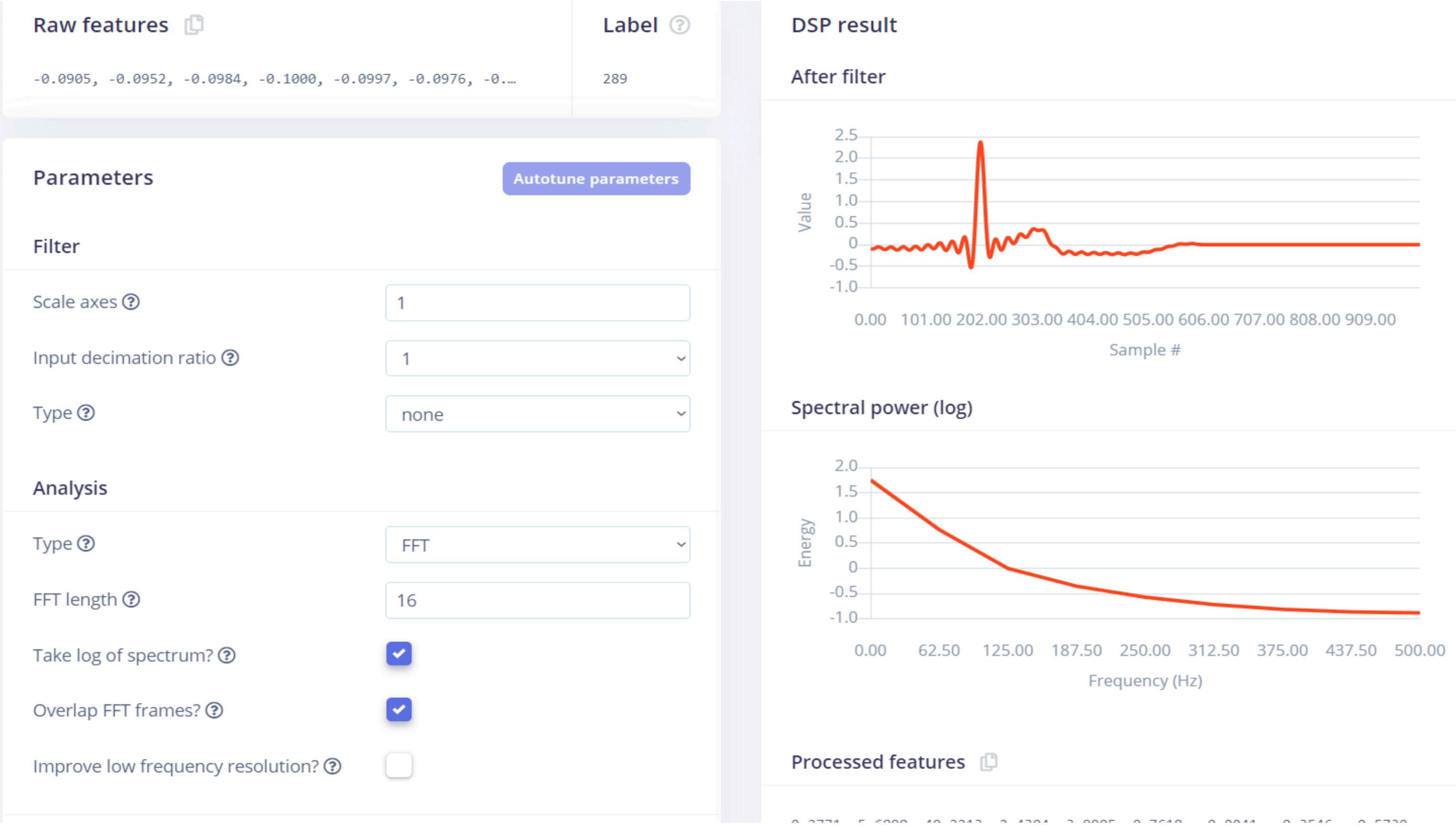


Image 3.2-2: DSP result for Spectral Feature

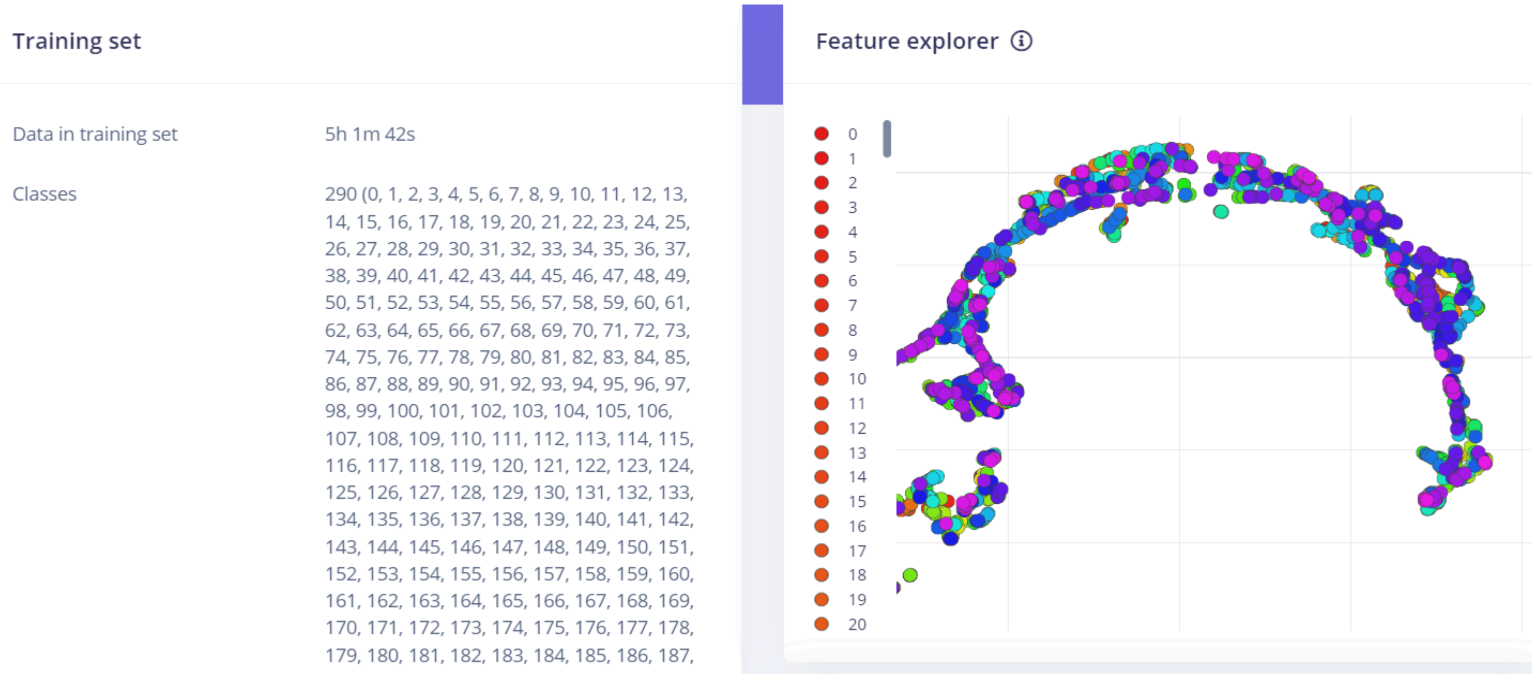


Image 3.2-3: Generate Feature Explorer Part 1

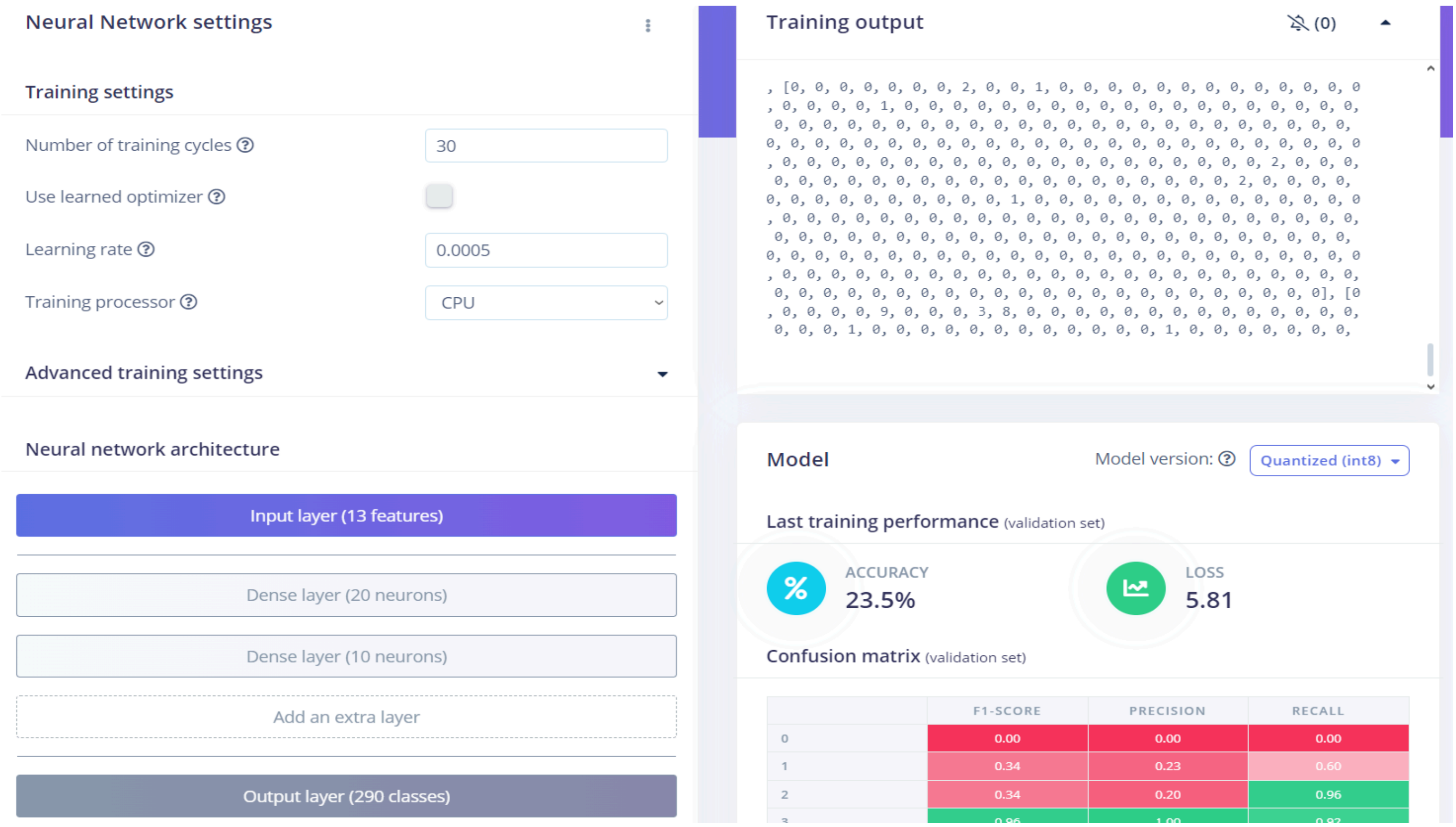


Image 3.2-4: Classifier for DNN Part 1

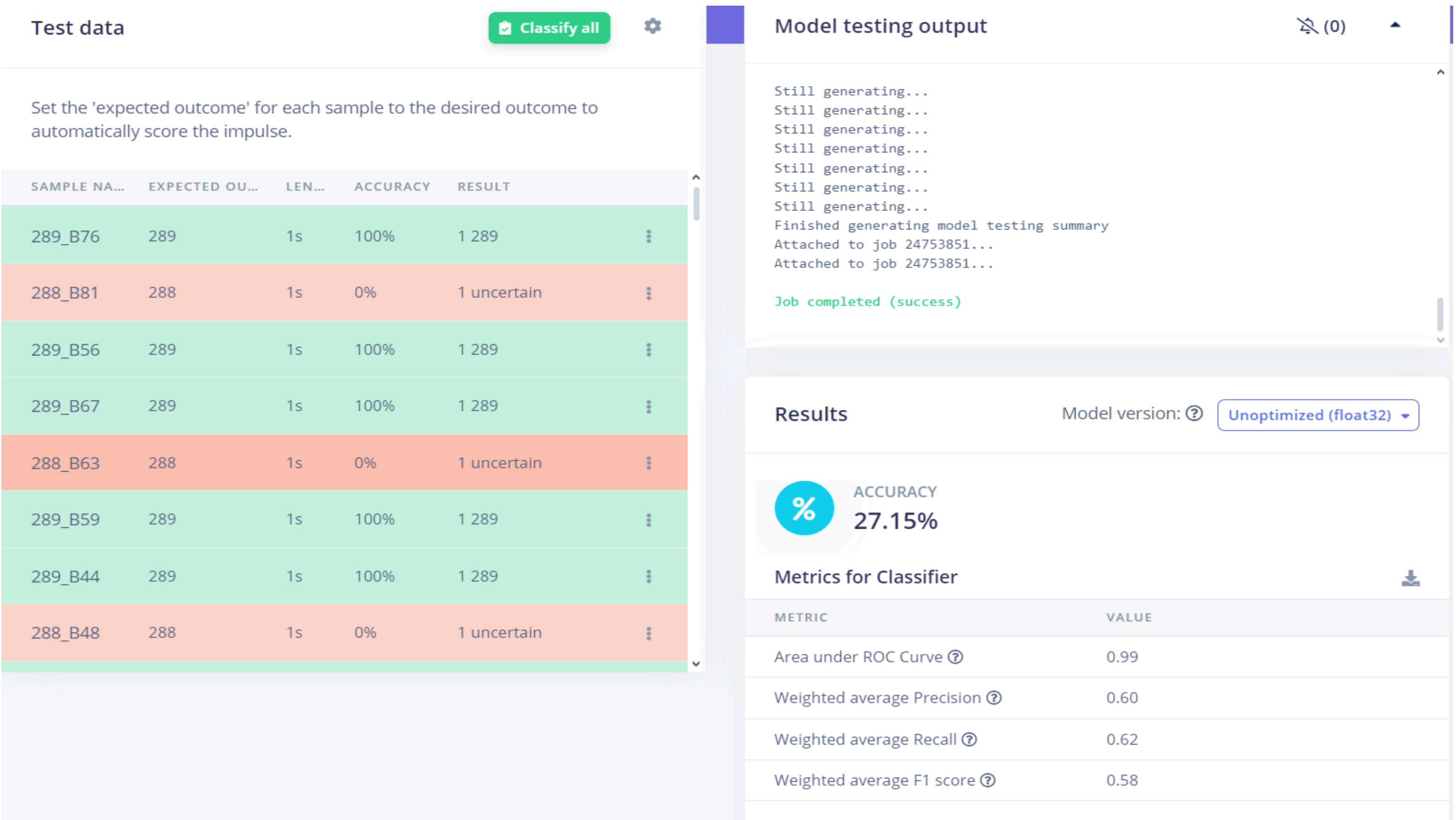


Image 3.2-5: Model Testing Part 1

3.3 Experiment Images for Part 2

Image 3.3-1: DSP result for Spectrogram features.

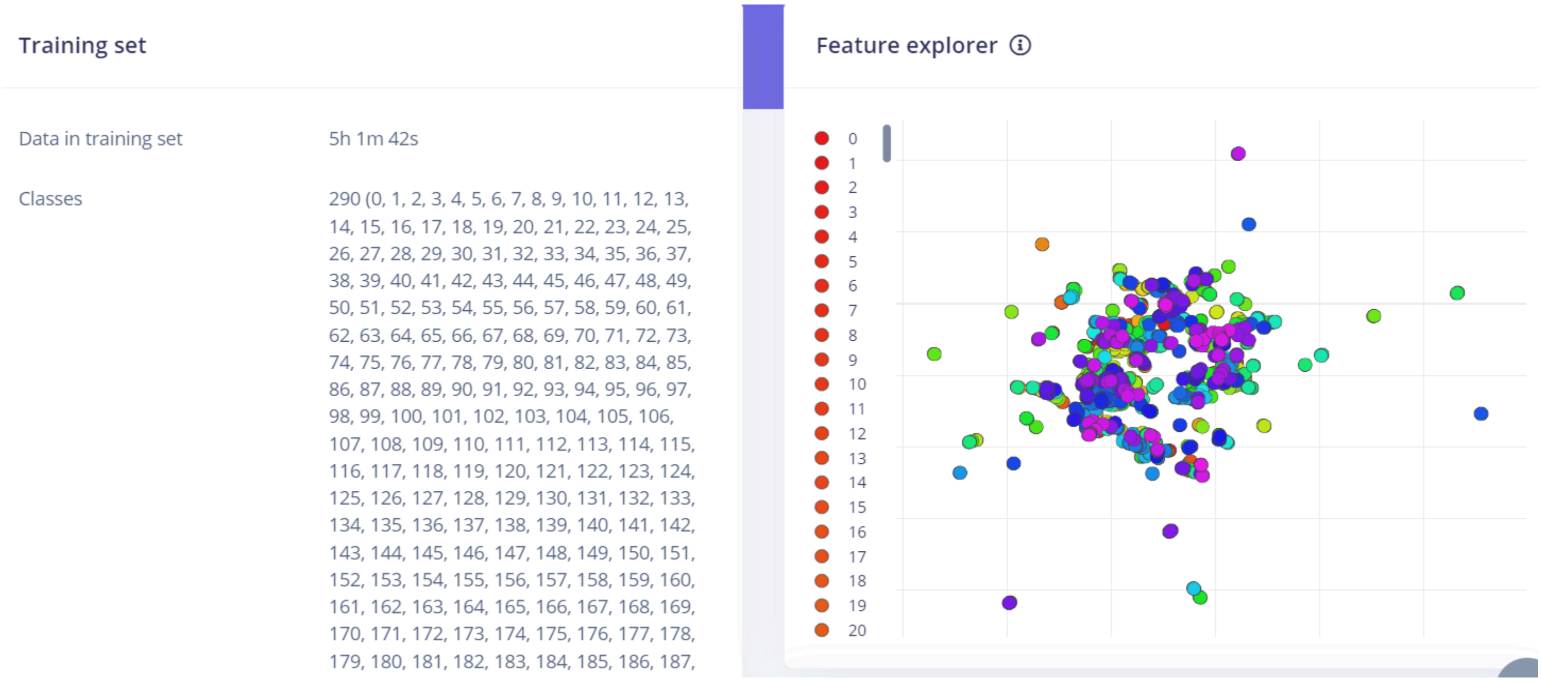
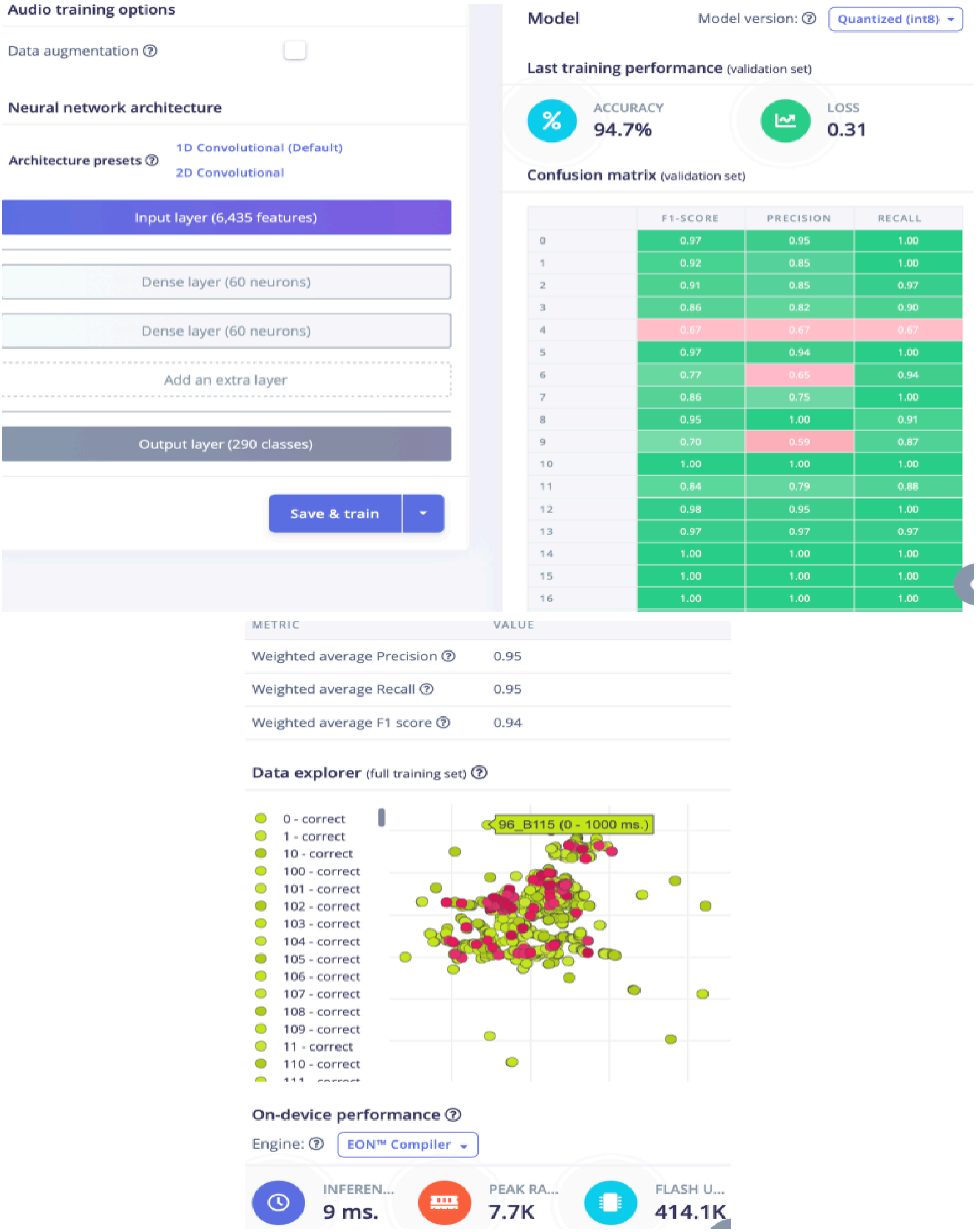


Image 3.3-2: Generate Feature Explorer for part 2



	F1-SCORE	PRECISION	RECALL
0	0.97	0.95	1.00
1	0.92	0.85	1.00
2	0.91	0.85	0.97
3	0.86	0.82	0.90
4	0.67	0.67	0.67
5	0.97	0.94	1.00
6	0.77	0.65	0.94
7	0.86	0.75	1.00
8	0.95	1.00	0.91
9	0.70	0.59	0.87
10	1.00	1.00	1.00
11	0.84	0.79	0.88
12	0.98	0.95	1.00
13	0.97	0.97	0.97
14	1.00	1.00	1.00
15	1.00	1.00	1.00
16	1.00	1.00	1.00

METRIC	VALUE
Weighted average Precision	0.95
Weighted average Recall	0.95
Weighted average F1 score	0.94

Image 3.3-3: Classifier For DNN

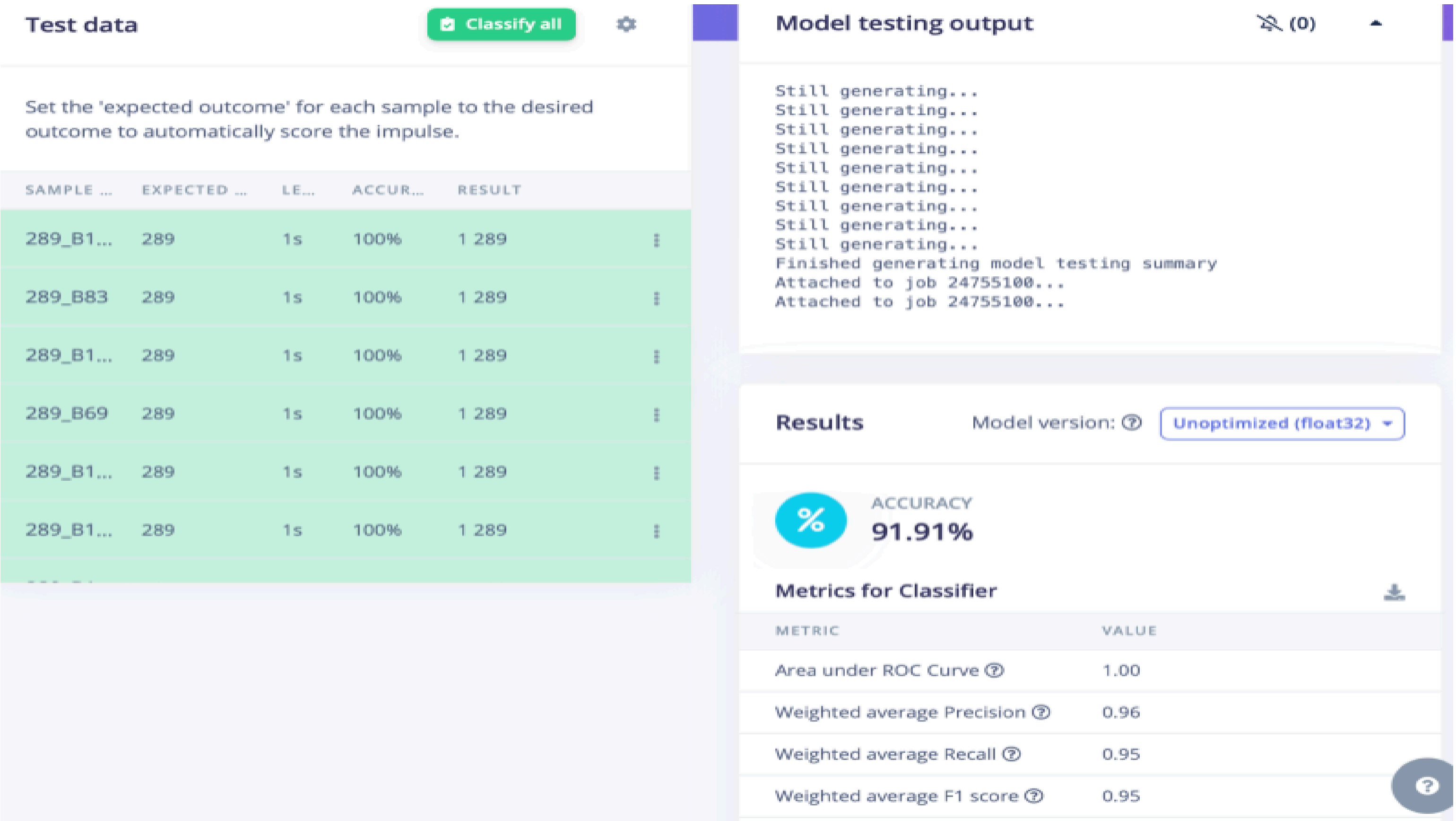
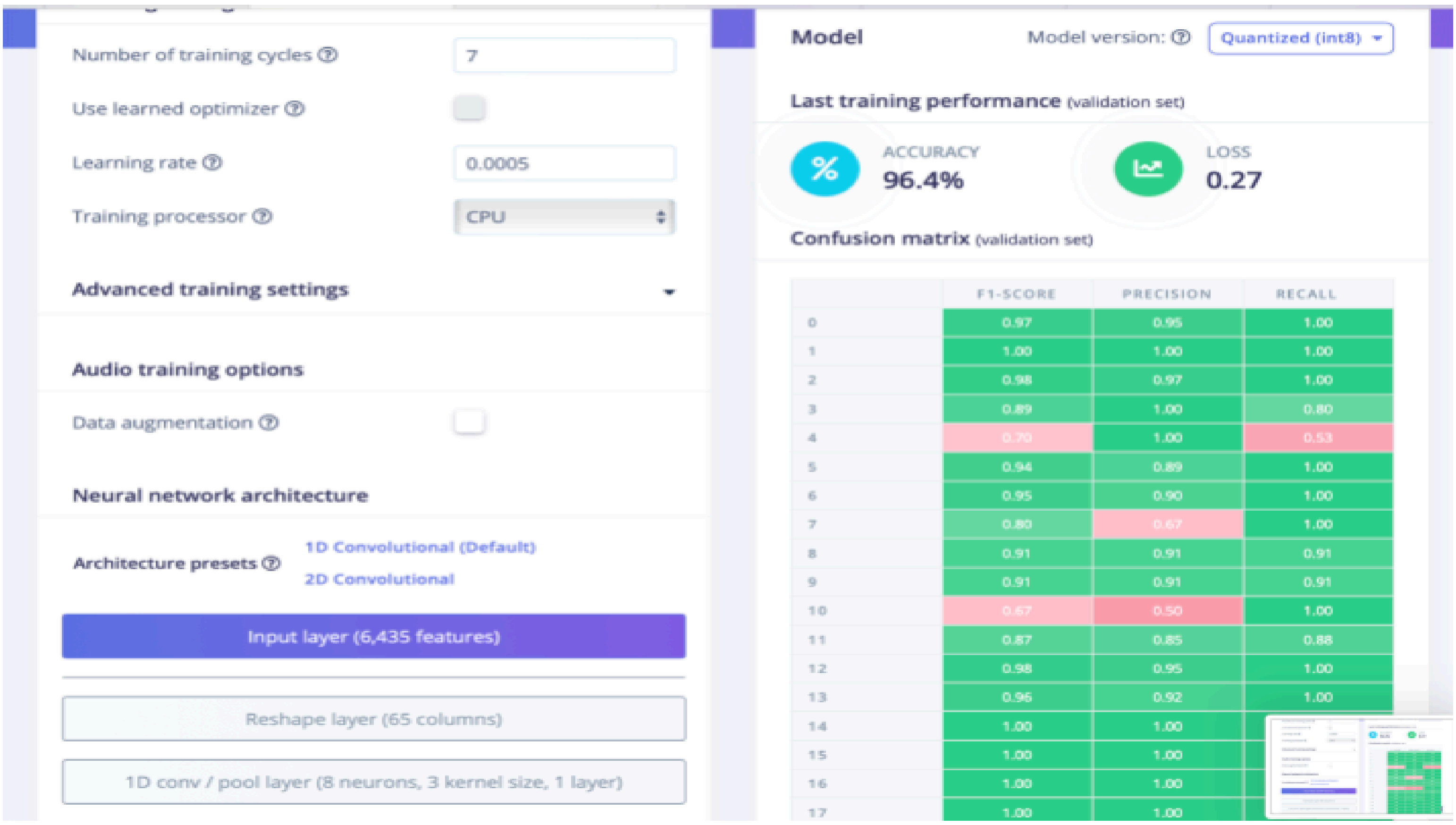


Image 3.3-4: Model Testing For DNN



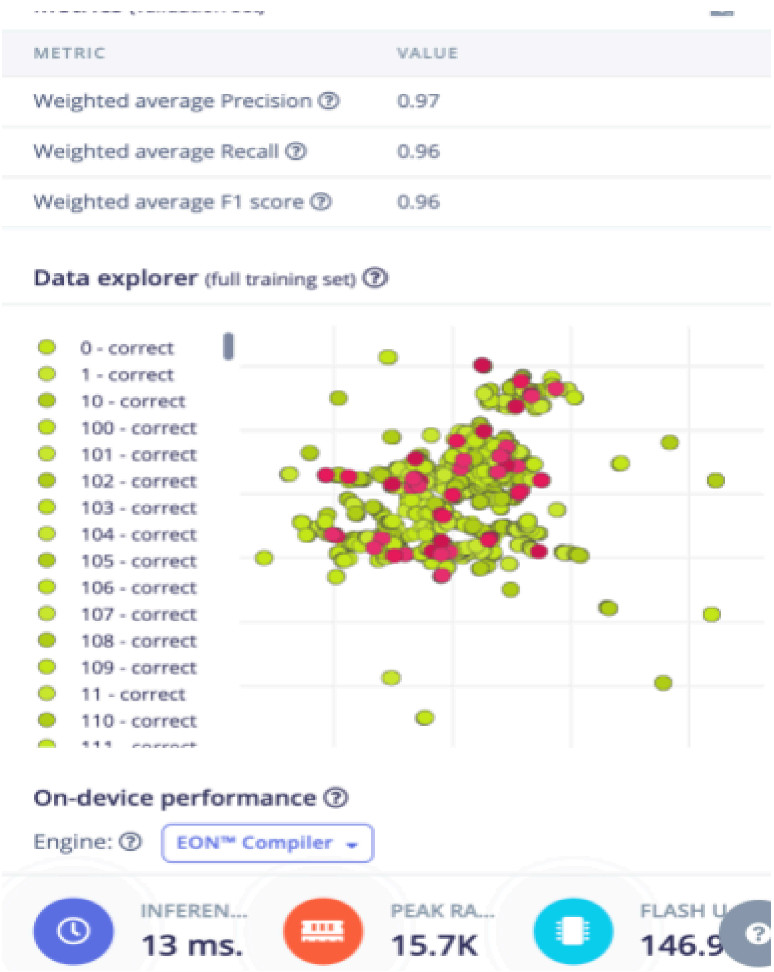


Image 3.3-5: Classifier For 1D CNN

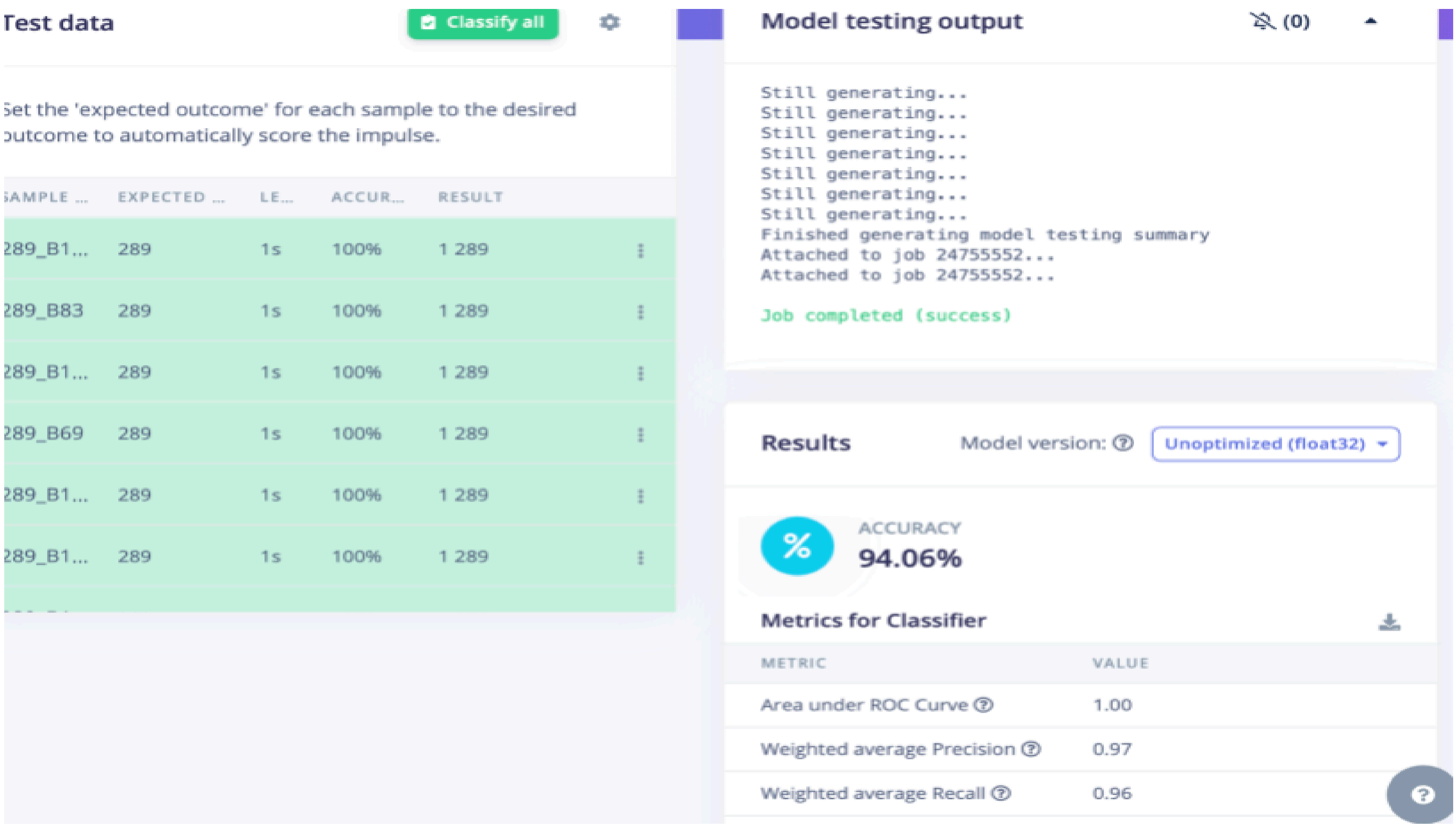
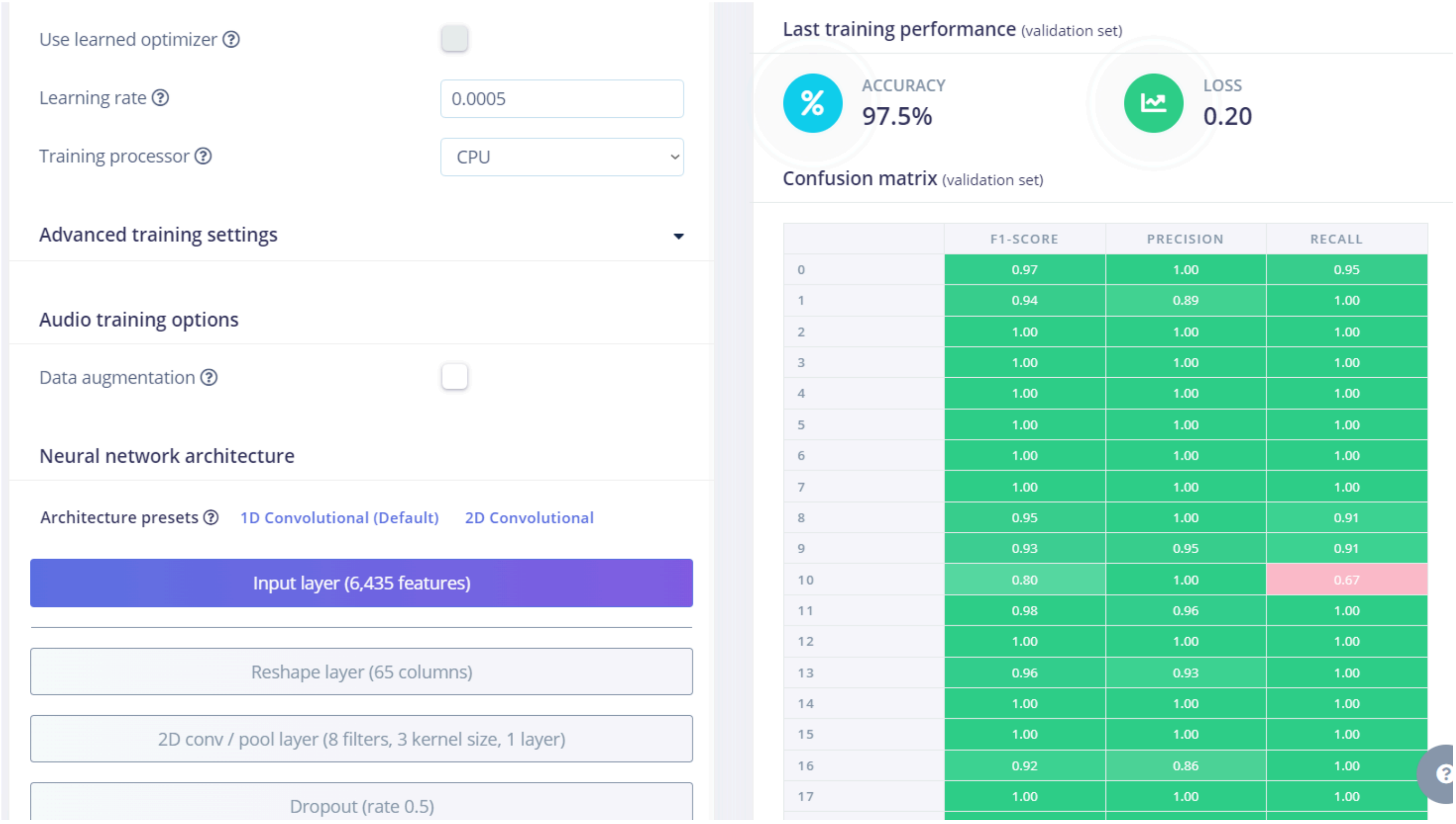


Image 3.3-6: Model Testing For 1D CNN



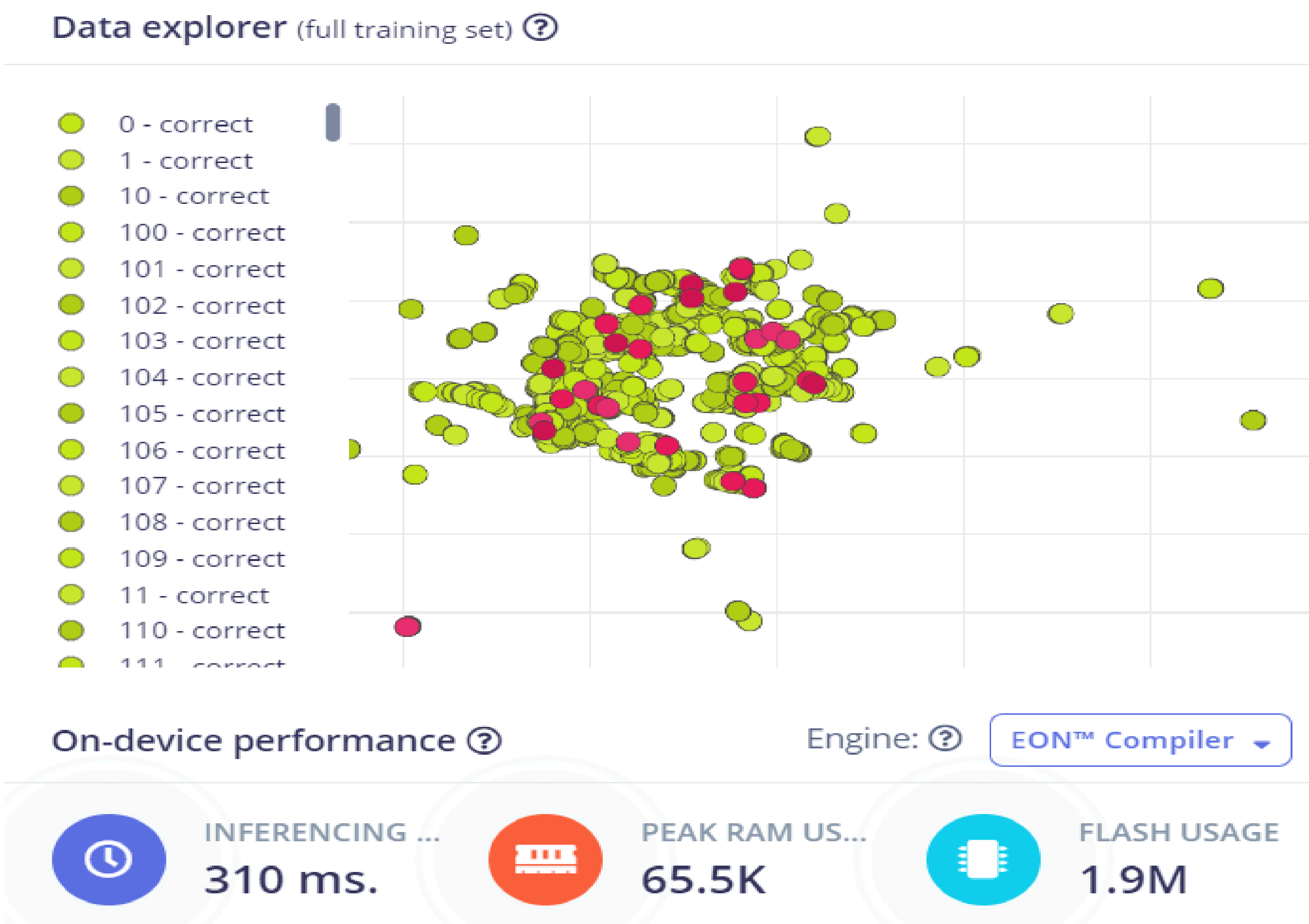


Image 3.3-7: Classifier For 2D CNN

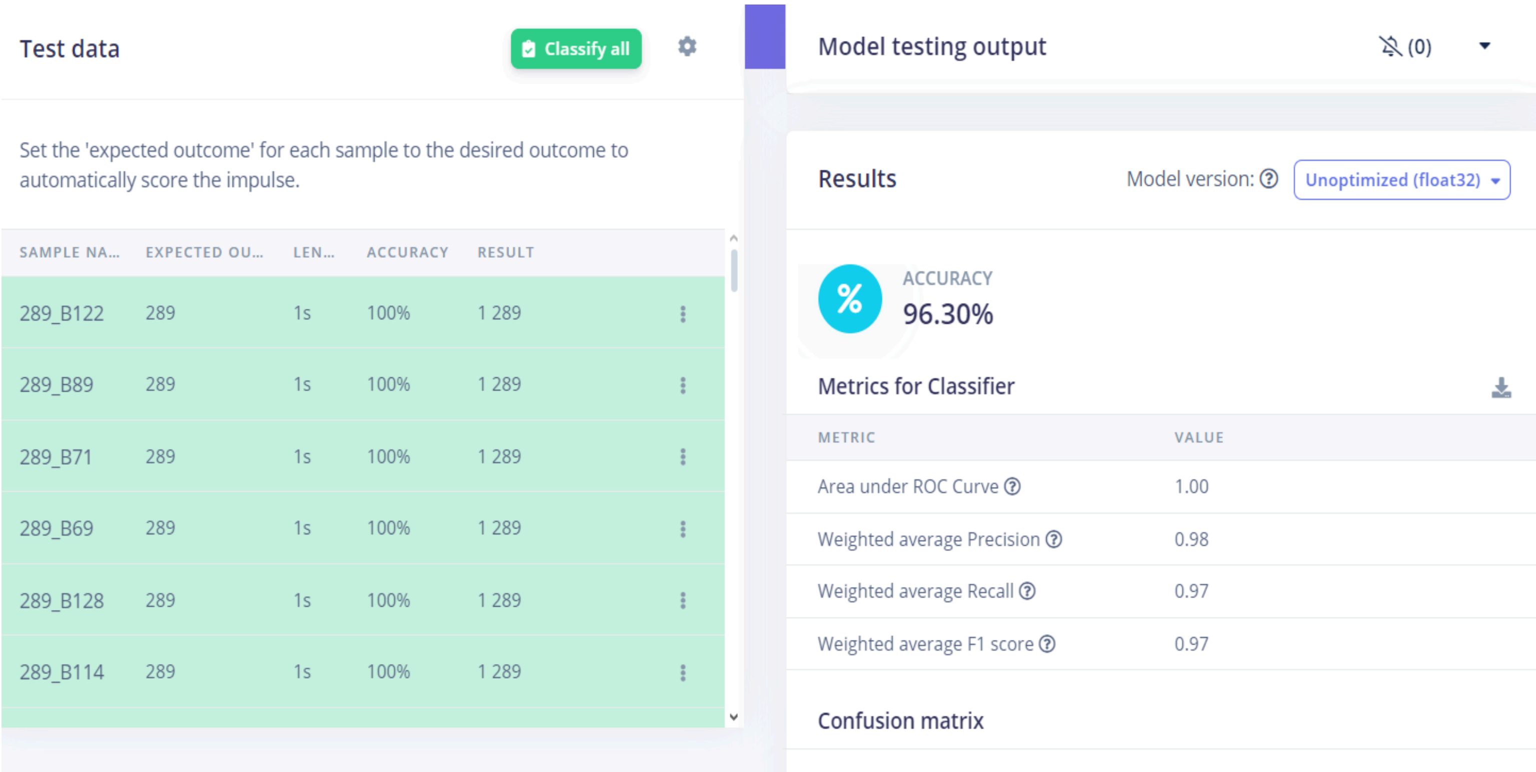


Image 3.3-8: Model testing For 2D CNN

4. Discussions and Conclusions:

4.1 Comparison of your experimental results with the research/theory of the concept with reasoning.

In signal processing, a spectrum is a representation of the frequency components of a signal, while a spectrogram is a time-frequency representation of a signal. The spectrum only shows the frequency content with corresponding amplitude in the overall time of a signal. However, the spectrogram is a 2D graph that implies amplitude (in color), frequency, and time. It can show the frequency-amplitude feature at any specific time within the data sample. In this lab, the data are ECG signals which exhibit complex dynamics. It is not enough to know the spectrum of one signal, but needed to know how the spectrum changes over time within one signal sample. Thus, to extract the features of ECG signals better, a spectrogram is chosen in data preprocessing. It helped to achieve the accuracy of the model above 94%.

4.2 Learnings from the experiment

The lab provided valuable insights into the classification of ECG signals using different feature extraction techniques and neural network architectures. One key learning was the importance of feature selection in ECG classification, where Spectral Analysis and Spectrograms demonstrated how different representations of the same data could impact model performance. This showed that choosing the right feature extraction method is critical to achieving accurate classification results.
The lab demonstrated how Edge Impulse can be an effective platform for deploying machine learning models on embedded systems. It enabled the comparison of various architectures in a real-world scenario, teaching the importance of balancing accuracy, resource constraints, and power efficiency when deploying models on devices like the ESP32.

5. References:

Wikipedia, https://en.wikipedia.org/wiki/Spectrogram
Hugging Face Hub documentation: https://huggingface.co/docs/hub/index
Edge Impulse: https://edgeimpulse.com/